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In This Issue:

Present Trends:

A paper under this title, read at the opening meeting of the sixteenth annual convention of the Association of Hawaiian Sugar Technologists, is given in this number. It deals with synthetic planning as a major need in industrial development.

Fruit Fly Investigations in East Africa:

Although failing in the attainment of its main objective, the introduction of new parasites of the Mediterranean fruit fly into Hawaii, the expedition dealt with in this article has made a valuable contribution to the recorded knowledge of the Trypetidae and their parasites. New host and locality records of well-known species are of value. In addition, according to the News Letter of the United States Department of Agriculture, Bureau of Entomology and Plant Quarantine, Vol. IV, No. 1, p. 27, 1937, the collections made by the expedition, representing 12 species of the genus Ceratitis and 13 species of the genus Dacus, comprise four species new to science in the former genus and five in the latter. There were, besides, two new species of Trypetidae from other genera than Dacus or Ceratitis, and a number of new parasites which are noted in the present article.

Selection of Seedlings:

The relationship of plantation economics to juice quality, closing-in ability, ease of harvesting, and other varietal characteristics is a subject which becomes especially urgent under the prevailing conditions of labor shortage.

In this paper Mr. Conant presents an enlightening analysis of the subject, together with tables which will facilitate further study in this direction.

A New Species of Pyrophorus:

Celebrated in the songs and folklore of the West Indies and Central America for centuries past, the friendly "cucuyos" now have a chance to become equally well

known in regions far removed from their original home. Here is presented an account of the introduction of one species into our own Hawaiian Islands. More recently a closely allied and better known species, *Pyrophorus Luminosus* Illiger, was introduced from Puerto Rico into the Island of Mauritius—it will be interesting to compare the respective records of the two species in their new homes.

Absorption of Mineral Nutrients by Sugar Cane at Successive Stages of Growth:

Sugar cane does not take up all mineral nutrients at constant rates throughout the growth of the crop. While certain elements are absorbed at uniform rates, after the first three months, others are taken up rapidly during the early months of growth, but later at reduced rates. The results of the study lead to the conclusion that the requirement of sugar cane for nitrogen is very pronounced during the early months of growth, but that subsequently much more moderate quantities of the nutrient will suffice to permit optimum growth.

Chemical Analyses as an Aid in the Control of Nitrogen Fertilization:

Supplementing R.C.M. available soil nitrogen investigations conducted on plantations by individual agriculturists and the agricultural and chemistry departments of the Experiment Station have cooperated in conducting a number of pot experimental studies. These experiments were designed to furnish information pertinent to the application to field problems of data determined by rapid chemical analyses. The investigations dealt with two aspects of the nitrogen problem—soil variations and soil-plant relationships.

These studies indicate that in a given soil, the available nitrogen content fluctuates during short intervals and over seasonal periods. Where nitrogen has been applied to soils supporting growing cane, the available soil nitrogen content is usually low due to plant absorption, which may be very rapid. As a result of these studies, a procedure is suggested for the practical application, in fertilization, of available soil nitrogen data obtained by the R.C.M. (rapid chemical method) of analysis.

Trends in Irrigation Practice:

The ever-increasing popularity of long lines in sugar cane irrigation is demonstrated in the survey of irrigation practices made in the summer of 1937. Since 1932 the area irrigated by this method has increased almost fivefold. The use of two-line borders has been widely extended as well.

Although the acreage served by overhead sprinkling has decreased markedly since 1932, it seems highly probable that a small four-acre tract served in this way at Waialua Agricultural Company will point the way to revived popularity.

This paper is the third of a series of three devoted to statistical surveys of sugar cane irrigation in Hawaii. The first two were presented at the Annual Meetings of the Hawaiian Sugar Planters' Association in 1931 and 1932.

Present Trends*

By H. P. Agee

A discussion of present-day trends brings us to consideration of the future—to a contemplation of its problems in an attempt to discern the approach toward their solution.

An intelligent consideration of the future causes us to drop back a little in order to gain our perspective, to align our focus, to establish the composition of what we have before us.

Composition acquires a special meaning as used by artists with reference to their pictures. It has to do with the manner of combining elements to form a whole. It considers balance and coordination. It deals with contrasts homogeneously brought together.

Yet, technologists, no less than artists, are concerned with *the whole of the picture.* In attending to their respective spheres of activity, chemists, engineers, agronomists; botanists, geneticists, pathologists; entomologists, physicians, dietitians; accountants, legal advisors, financiers; are each working upon a section of that whole, yet they cannot consider their work as fragments: they are intimately concerned in appropriately shaping parts—in developing closely related segments of a single comprehensive enterprise.

We call it *agriculture*—this business we conduct in Hawaii, yet we seldom pause to think in terms of what that agriculture has come to be.

As we consider the agriculture of the world generally we become more and more impressed with the fact that we have here something different—we have a new phase of agriculture—a phase that brings the tilling of the soil to the forefront with other lines of activity. We have the large unit, as do manufacturing and transportation and merchandising elsewhere, and thereby the interests of many are pooled for the sake of the opportunities for protection, and the opportunities for advancement that such pooling affords.

Agriculture in Hawaii lives, if we bring it down to a few words, by reason of these three things: (1) cooperation, (2) specialization, (3) coordination. The first of these, *cooperation,* expresses a coming together for united effort. The second, *specialization,* signifies a breaking apart of the whole in a fact-finding search, and a fact-found attack by those specialists particularly qualified for their individual tasks. *Coordination* implies a binding together of those specialties to function as one.

This agriculture merits praise but we do not have the perfect machine. This group is concerned to make it better than it is.

I want to speak of specialization. We have an industry of specialists. I have already named a number of them and either you or I could name more.

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* A paper read at the meeting of the Association of Hawaiian Sugar Technologists November 15, 1937.

There are a number of ways in which we might group these specialists of our industry. I like to think of them as, (1) people engaged in developing new basic information, (2) people engaged in finding practical applications of the information we have and in solving the problems of application and adaptation, and (3) people engaged in performing some well-established lines of work or in supervising and checking their performance.

This grouping covers our specialists from the man engaged in the business of freeing a field of sugar cane of its weed growth to the engineer, chemist, or entomologist in his laboratory. There are no sharp dividing lines between the problems of research, application, and performance; no separating gulfs between the issues of investigation, adaptation, supervision and inspection.

The spirit of science should permeate all of them. Science in its clearest and best definitions has nothing about it that is mysterious or obscure. Science means getting at the truth, finding out the facts. Applied science means action based on the facts as they have thus far been revealed.

All of us are specialists in that each of us has undertaken to perform some particular piece of work, and needs to know the reason for that work and the relationship of it to other work that bears directly or indirectly upon it.

Each of us is a scientist in that we are each intimately concerned with facts—with ascertaining the truth and putting it to use.

As specialists we are concerned with the weaknesses of specialization as well as the strength of it. All who have read Alexis Carrel's *Man, the Unknown* (Harper and Brothers, New York and London, 1935) are impressed by his splendid constructive criticism of specialization. He speaks particularly of medicine and medical research but what he says is broadly applicable.

"The science of man," he tells us, "makes use of all other sciences. This is one of the reasons for its slow progress and its difficulty. . . . Obviously, no one scientist is capable of mastering all the techniques indispensable to the study of a single human problem. . . . Specialization is imperative. . . . But it presents a certain danger. . . . Modern civilization absolutely needs specialists. Without them, science could not progress. But, before the result of their researches is applied . . . the scattered data of their analyses must be integrated in an intelligible synthesis."

By synthesis he means the putting together or combining of related parts to form a well-ordered whole, and the work of doing this, Carrel tells us with great positiveness, is essentially the character of work that calls for continual and uninterrupted attention of the individual mind, as distinguished from work that may lend itself to group activity.

". . . a synthesis," he says, "cannot be obtained by a simple roundtable conference of the specialists. It requires the efforts of one man, not merely those of a group. A work of art has never been produced by a committee of artists, nor a great discovery made by a committee of scholars. . . . Today there are many scientific workers, but very few real scientists. This peculiar situation is not due to lack of individuals capable of high intellectual achievements. Indeed, syntheses, as well as discoveries, demand exceptional mental power. . . . Broad and strong minds are rarer than precise and narrow ones."

Carrel continues, "It is easy to become a good chemist, a good physicist, a good physiologist, a good psychologist, or a good sociologist. On the contrary, very few individuals are capable of acquiring and using knowledge of several different sciences. However, such men do exist. Some of those . . . forced to specialize narrowly could apprehend a complex subject both in its entirety and in its parts. . . . If the superiority of this kind of intellect were recognized, and its development encouraged, specialists would cease to be dangerous. For the significance of the parts in the organization of the whole could then be correctly estimated."

Thus does Dr. Carrel in fine emphasis relate the need of specialization, the danger of specialization, and the great importance of giving encouragement to the individual who reaches into several specialties and performs synthetic work—work of putting together in functioning form that which has been developed as a result of analytical study.

Management, we may say, is responsible for this coordinated planning, this piecing together of loose parts. However, an important executive once said, "The office boy has duties, I have interruptions." It is these inevitable unavoidable interruptions that often relegate the all-important business of planning to a secondary or incidental position. This gives us cause to heed what Carrel says of creating a new specialty—that of *synthesis*. This idea is gaining headway. May we list it as a present-day trend?

As an expression of that trend we have a gradually increasing number of assistant-manager appointments. Perhaps as this official becomes engulfed in interruptions we may look for some second assistants on the larger places. I shall be glad if the suggestion brings about some new well-paid positions. I hope there are among us apt candidates.

They should be men who can plan. The fundamental principles of planning are not commonly understood. The schools and universities do not teach planning. They take the accumulated knowledge of mankind and cut it into hundreds of parts and they do it very well. But they do not tell us how to piece parts together in a plan.

The elementary principles of planning are rather simple, yet carried into its further elaborations planning taxes the human mind for all it has to offer. Similarly does mathematics in its further reaches, yet we know that all mathematics is an elaboration of the simple idea that one and one make two.

Lasker set forth the elementary principles of planning as recently as ten years ago.* He tells us a plan conceived in the mind of man is a faulty plan. That is what the matter is with so many of our plans. A human mind has had the effrontery to evolve a plan!

There should, according to Lasker, be a reason for a plan: the reason is a valuation: and the reason for the valuation is again values. The values reveal the plan. The plan is, in effect, a resultant of these values. Failing to develop precise values we have recourse to estimates, and judgment based on estimates trends in the right direction. Also we encounter the so-called intangible values. We can not measure them, yet we must give weight to their influence. Under this head come the human values, the emotional and psychological and prejudicial values.

* Lasker's Manual of Chess—E. P. Dutton, New York.

It is our quality of so-called common sense that helps us in evaluating intangibles. Intuition is a wonderful thing to possess. It functions best in human relationships. As we carry its use into other fields we find need to give it the support of physical and chemical evaluations.

We undertake an enterprise: we study our values: the values indicate the plan: perhaps certain values are obscure or uncertain: as a result alternate plans develop: choice is made on the basis of comparative estimations.

We proceed with an enterprise: as an army going into battle we contact the inevitable counter forces: we develop information as we go as does the intelligence department of a general staff. There is much that we do not know: we go ahead on the basis of the known and estimated values and seek new values and revised evaluations as we proceed. We give heed to positional values, and recognize that the values of things change according to positions that they occupy in time and space.

This is not new. In some respects it is as old as human effort. Yet few of us follow our values with thoroughgoing persistence. We have not accepted a philosophy of values. It is easy to be led off track by our prejudice; our ego; our preconceived mind-formed plans; by our faulty evaluations; by our conservatism, perhaps, or by our daring.

We let our thinking become fettered by its subject matter. Are we content to remain chemists, mechanical engineers, executives, botanists, electricians, agronomists, accountants? Shall we assign our thinking to circumscribed zones as we assign policemen to beats or postmen to mail routes?

No. Primarily we are specialists in values. Secondarily, we are to draw upon the special training and experience of ourselves and others available for consultation. We are to seek values with which we are intimately concerned regardless of the department of knowledge in which the university has chosen to place them. Pasteur did this. Either he thought broadly because he was a genius, or else he is considered a genius because he thought broadly, precisely, imaginatively.

The difficulties that Carrel describes for a single human mind to reach into several sciences and make use of them synthetically, begin to melt away under this approach. Imagination, that rare quality, reduced to its simplest terms, consists in finding things that fit together and joining them to attain some end. We assert this quality in crude form in solving the jigsaw puzzle. Also we assert it as we develop new ways to gain ground in football; when we find a combination in chess; when we put words or musical notes together in new apt ways. Similarly our great inventions and important discoveries are in last analysis other forms of combination. Perhaps, as with Pasteur, the field of human knowledge is expanded to find basic facts to be brought together.

Creative work, so called, is in reality combinative work as Reti has so ably indicated.

Imagination in industry starts from the premise that current methods and situations are but the phases of today in a moving panorama of events. It differentiates between effort and accomplishment, attempts to strip performance of unessential labor and expense. It forecasts the problems of tomorrow and prepares for them.

The imaginative viewpoint in sugar production takes account of our cultivation practices, fertilization, irrigation, and weed control, in all their varied forms, and

of our choice of sugar cane varieties. It relates these to soil properties, topography, elevation; to cropping cycles, crop lengths, time of crop starting, time of harvesting; relates all in turn to weather variability, makes quantitative measurement of effective temperature and sunlight; it works in terms of the most effective balance between cane tonnage and juice quality; in terms of available man power, available brain power; in terms of mechanical equipment, present and prospective; in terms of costs and market value of our product; in terms of crop quotas; in terms of plantation population welfare and community relationships.

Thereby it encounters a rich and complicated interplay of values from which the plan of action is to be deduced—of necessity a mobile plan to be changed to conform to the mobile values upon which it is based. It studies the whole field of values assiduously, provides investigation and research to explore the outer, darker reaches of that field.

A few days ago I was talking with a man from one of the other Islands. We touched upon trends of the day in sugar production. He felt things were on the decline technologically speaking, that government quotas, labor disturbances, grab harvesting and the consequently poorer mill recoveries, were taking us backward as technologists.

I take issue with that viewpoint considering our problems in the light of bringing to bear upon them our best knowledge and resources. A strategic retreat may call for the finest there is in generalship and an advance merely for the sake of going forward is oftentimes a foolhardy thing to attempt.

Mention has been made of cooperation, specialization, coordination. Let us add that other cardinal need—realization of objective.

Our ultimate objectives remain more or less fixed, our immediate objectives shift and change and thus they tax us for the best we have in planning capacity.

In games we are quick to denote a needed change in immediate objective: we should be equally alert to do so in industry.

A few years ago the Hawaiian plantation was free to market all the sugar it could produce. Each additional ton added to its crop was a welcome ton in so far as the necessary cost of production of the added ton came sufficiently within the selling price to carry a profit. And so we went in for higher and higher yields and higher and higher recoveries.

Then we had the quotas of 1934 and a labor surplus for a time. That threw our objective to the low-cost ton of sugar.

There came an expansion of the quotas, wet years with heavy weed growth, and with them some labor disturbances. Out of this has come a wider use of herbicides. Out of it has come grab harvesting. Only a few months ago the cane harvester was a far-away dream. Then we find that we have in our own back yards, so to speak, equipment that can harvest cane mechanically. Having been blocked all these years by the difficulties of mechanically cutting, trashing, and topping cane, under the new approach we forget all about these stumbling blocks, and grab it, snap it off as best we can, and send it to the mill with its tops and trash, its stones and mud and *honohono*.

It is needless to say to a group of technologists that this approach carries with it a host of new problems. Opinions vary widely on the future of cane grabbing.

Some think of it as a permanent institution in the dry, heavy-yielding lands, and question its application elsewhere. Some look upon it as an expedient in an hour of need, except perhaps for the favored locations. Others optimistically hold that grabbing cane is here to stay—that it is to have wide application—that the difficulties of lower recoveries and congested boiling houses are somehow to be met.

A revolutionary step that cuts the bonds that have held our thinking can lead the way to much that is new in a short time, and no one can predict what another twelve months will bring forth.

Back of this question, as back of all questions, we have our pertinent values—values to be painstakingly sought and estimated and carefully applied to our planning. A plantation that has capacity to produce more sugar than it has the privilege to market, can sacrifice recovery to attain quota under labor limitations. We have in a new form the age old problem of balance—it is an issue of balance in values.

It should be a good gathering—this sixteenth annual meeting of the Association of Hawaiian Sugar Technologists, with so much before us that is new, so much that is in prospect.

Technologists are, of course, greatly interested in high recoveries and maximum yields where the play calls for these. We are equally interested in acceptable sacrifices in recovery or yield per acre, when the game, if well played, brings these into account.

I trust that your deliberations this week will be most instructive and successful and that you will return to your plantations with a better understanding of the problems that are before us, better qualified to discern your objectives, better able to bring about cooperation, specialization and coordinated performance, better fitted to assist in synthetic planning.

Thus you will participate in putting Hawaiian sugar production on a higher plane of excellence, considered from the standpoint of the whole of the picture, and thus will you help to make the plantations better places to live for the thousands who make their homes upon them.

Recent numbers of *Life* (October 18 and 25, 1937) give some inspiring notes about inventor Kettering. These I give in part:

> He remembers he was the "dumbest kid in the whole school" when he started arithmetic in the tumble-down schoolhouse of his youth. He finally completed college in 1904 at the age of 28, threw his diploma in the wastepaper basket, decided he was going to start learning, and took a job with National Cash Register Co. of Dayton, Ohio.
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> Considered a monkeywrench scientist up to wartime, he is today the idol of young engineers, the pride of General Motors, who made him vice-president in charge of research, and the man most responsible for making the automobile a necessary luxury. He puts the fear of God into businessmen because his mania for progress makes plants and machinery obsolete as soon as they are erected.
>
> Today at 61, Kettering feels he now has the equipment and necessary basic facts to do something.
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> To science pundits who say "It can't be done," he answers, "The hell it can't!" Then he tries, fails, tries again until finally it is done. He scorns the mystical halo of science, the awkward, ponderous nomenclature of scientific language.

Despite his laughing at "pure science" his versatile mind delves into all its phenomena. "Research," he says, "is finding out what we are going to do when we can't go on doing what we are doing now."

He has seen his visions come true, has new visions. To science he delegates the job of making this a finer world. Says he, "I belong to a group of men who believe the world isn't finished. Nothing is constant but change. We work day after day, not to finish things, but to make the future better . . . because we will spend the rest of our lives there."

In conclusion, gentlemen, I suggest we join that group.

Fruit Fly Investigations in East Africa

By F. A. Bianchi and N. H. Krauss

Here are summarized the findings of the East African Fruit Fly Expedition undertaken by the writers for the United States Department of Agriculture during the latter part of 1935 and the first half of 1936. These findings have already been presented in an official report, but with the addition of identifications for most of the fly and parasite material, only recently completed by the Taxonomic Division of the United States Bureau of Entomology, their usefulness and interest are greatly enhanced.

The four countries visited in the course of the work are dealt with under separate headings.

Tanganyika

Four localities, ecologically widely different, were investigated as follows:

The Tanga Plains:

In the Tanga Plains were investigated the environs of a number of small villages and one large plantation—Sigi-Sigoma. Most of this country is under 1,000 feet elevation and the climate is distinctly tropical with a high average temperature and two clearly marked and rather short rainy periods during the year, March to May and October to December. The supply of fruit was neither very abundant nor greatly varied and consisted mostly of non-indigenous species more or less cultivated. Particularly striking was the fact that in Tanga neither mangoes nor tropical almonds (*Terminalia catappa* Linn.), both very abundant, were ever found infested by fruit flies, although in Hawaii and other countries they constitute important hosts of these pests.

Our stay in Tanga lasted from November 14, 1935 to April 3, 1936 but was interrupted by several short visits to other places.

Following are listed the sources of fruit flies and parasites in this area:

Coccinea sp.: A cucurbitaceous vine with red fruits about two inches long, probably indigenous and not uncommon in weed-grown areas. On one of many occasions when it was examined the fruit yielded *Tridacus vertebratus* Bez. but no parasites.

Psidium guajava Linn. (Myrtaceae): The ordinary guava, not nearly as abundant in Tanga as in Hawaii, and found forming a thicket only on one occasion, proved infested by *Ceratitis colae* Silv. but produced no parasites.

Luffa sp.: Unlike *L. aegyptiaca* this cucurbit had smooth fruit without ribs or warts. It was heavily infested by *Tridacus pectoralis* Walk. but produced no parasites.

Oranges: Shared with mangoes and tropical almonds the distinction of being the most abundant fruit in Tanga and were occasionally found infested by one or more species of Ceratitis which always proved difficult to rear and for which we have no identification.

Cordyla africana Low. (Papilionaceae): Sparsely infested with *Ceratitis cosyra* Walker, of which some 20 per cent of the pupae proved parasitized by *Opius perproximus* Silv.

The East Usambara Mountains:

Visited from November 14 to December 12, 1935, and for shorter periods on several other occasions up to March 1936. Worked mostly in the vicinity of the East African Agricultural Experiment Station, Amani, at elevations of from two to three thousand feet. With the same two short rainy seasons but heavier rainfall than Tanga (80.09 inches, annual mean) and much lower temperature (68.2 F.), this area is heavily wooded and provides a great variety of native as well as introduced species of fruit. Unfortunately the quantity available was not great.

The following fruits were sources of flies and parasites:

Sersalisia usambarensis Engl.: A native sapotaceous tree nearing the end of its fruiting season when we first arrived in Amani. The tree attains a height of 60 feet or more and produces large quantities of an olive-sized fruit—red, brittle-shelled, and extremely attractive to the destructive hornbills, the most conspicuous birds of the region. From about 250 pounds of the fruit we reared *Ceratitis punctata* Wied. and *Ceratitis colae* Silv. and obtained from the mixed pupae of these flies, which we were unable to distinguish before the emergence of the adults, two parasites, *Tetrastichus dacicida* Silv. and *Opius perproximus* Silv.

Psidium cattleianum Sabine. (Myrtaceae): From 20 or 30 pounds of this fruit, the common strawberry guava, all from one cultivated grove, we reared large numbers of *Ceratitis capitata* Wied. and *Ceratitis colae* Silv. The incidence of fly attack was almost 100 per cent, but the per cent of parasitism, by *Opius perproximus* Silv., was practically nil, only nine or ten parasites emerging from all the material.

Psidium guajava Linn. (Myrtaceae): Although even scarcer in Amani than in Tanga, guava trees seemed to produce much larger crops in the former place. We were told the fruiting season lasted from April to October. *Ceratitis colae* Silv. was reared from the fruit. The incidence of attack was high, but no parasites were observed.

Myrianthus arboreus Beauv. (Moraceae): A small indigenous tree with digitately divided leaves and a limited quantity of yellow, annona-like, semi-edible fruit of some four or five inches in diameter. Produced large numbers of both *Ceratitis rubivora* Coq. and *Ceratitis colae* Silv. but no parasites.

Dioscoria macroura Harms. (Dioscoreaceae): A green, irregularly shaped fruit about two inches in diameter, growing on a small tree. Only a small quantity was found from which were reared a few specimens of *Tridacus pectoralis* Walker but no parasites.

Momordica sp. (Cucurbitaceae); Marrow (Cucurbitaceae); Coffee (Rubiaceae); Avocado (Lauraceae); Roseapple (Myrtaceae); and two scarce and undetermined fruits yielded from one to several specimens of fruit fly species for which we have no identifications. The fruit fly or flies reared from marrow showed parasitism by an unidentified parasite.

The West Usambara Mountains:

Visited four days during December 1935. A range more or less parallel to the East Usambaras, separated from them by a deep narrow valley and 70 miles farther inland. In the locality where investigations were conducted, Lushoto, about 5,000 feet elevation, the native forest has been almost entirely displaced by bush and cultivated crops peculiar to the temperate zone, including several species of temperate zone fruits. Among the latter, plums, apples, strawberries, blackberries, mulberries, grapes, and peaches are prominent; but only peaches were obtainable when Lushoto was visited by us. From 40 or 50 pounds of this fruit, with almost 100 per cent incidence of infestation, was reared *Ceratitis colae* Silv. but no parasites.

Arusha:

Visited by Bianchi from March 21 to April 13, and from June 4 to June 23, 1936. With an elevation approximately the same as that of Lushoto, Arusha is ecologically different because of its remoteness from the coast (350 miles) and its proximity to the great extinct volcanoes Meru and Kilimanjaro, the latter being perennially snowcapped. Mean annual temperature is lower (64.8 F.) than in Lushoto and rainfall is less (44.18 mean annual inches) with two short and poorly defined rainy seasons separated by two drier periods. The region is noted as a coffee-growing center and also produces small quantities of the same temperate zone fruits found in Lushoto. As neither the vast uncultivated plains within easy reach of the town nor the equally accessible and beautifully wooded slopes of Mt. Meru proved bountiful sources of native fruits, most of the investigations dealt with these temperate zone fruits. The results follow:

Peponium sp.: A semi-edible Cucurbit, orange-colored when fully matured, somewhat like a common cucumber and growing on similar vines; a common and conspicuous component of brush thickets covering large areas of fallow land. This very abundant fruit showed high incidence of infestation by *Dacus eclipsis* Bez., *Tridacus pectoralis* Bez., and *Tridacus punctatifrons* Karsch. but never any parasites.

Undetermined Cucurbit: Fruits small, about one-half inch in diameter, pear-shaped, light green when unripe, with white longitudinal stripes when mature, growing on a roughly pubescent, small-leafed vine. Only two vines seen, one on the plains near Arusha, the other 3,000 feet higher up the slope of Mt. Meru in dense forest. From the latter was reared *Tridacus humeralis* Bez. which was attacked by *Tetrastichus giffardi* Silv. and an undetermined species of Opius. Both the incidence of fly attack and the percentage of parasitism were high.

Oranges and Common Guavas: Fairly abundant; yielded *Ceratitis colae* Silv. Fly incidence was high in guavas, very low in oranges. No parasites were reared from either fruit.

Himalayan Blackberries and Peaches: Both obtainable only in small quantities; yielded *Ceratitis rubivora* Coq. but no parasites.

Psidium cattleianum Sabine: The ordinary strawberry guava; few and widely scattered trees in private gardens; in one locality proved infested by *Ceratitis capitata* Wied. Ten pounds of the fruit with an estimated fly incidence of 80 per cent yielded eight specimens of *(Hedylus) Opius giffardi* Silv.

Coffee: It was said that ripening of the 1936 crop was held back by a protracted spell of cold weather. Due to that fact, perhaps, it was not possible to rear any of the parasites mentioned by the late A. H. Ritchie (Annual Report of the Tanganyika Department of Agriculture for 1934, page 77). From about 150 pounds of berries, hand-picked mostly from three particular sources, were reared four or five hundred flies of two species, *Ceratitis rubivora* Coq. and *Ceratitis colae* Silv. The incidence of attack was not high but is said to rise enormously as ripening of the crop progresses, the abundance of fly larvae sometimes hindering the depulping process.

Zanzibar

Zanzibar is an island with a surface extension of 640 square miles and a highest elevation of 440 feet. It lies only 25 miles east of Tanganyika and has a climate very similar to that of Tanga, but because of its dense population and other reasons the island enjoys ecological conditions different than Tanga's and provides a much greater variety and abundance of cultivated fruits. Unfortunately it soon became evident here, as elsewhere, that cultivated fruits were not often infested with fruit flies and that these, in cultivated fruits, were seldom heavily parasitized.

Zanzibar was visited by Bianchi from December 3 to December 12, and by Krauss from December 18, 1935 to January 5, 1936.

Out of a very long list of fruits available, only the following proved infested:

Psychotria sp. (Rubiaceae): A small red berry growing on vines near the north end of the island; locally called "Umjoma"; probably indigenous; quite scarce. Yielded a species of Ceratitis new to science, parasitized by a species of Opius, also new to science, and by *Spalangia afra* Silv.

Psidium guajava Linn: Common guava; scarce; the trees did not produce abundantly and were found mostly near habitations, more or less under cultivation. Yielded *Ceratitis capitata* Wied. and *Ceratitis colae* Silv. but no parasites.

Luffa aegyptiaca Mill., *Momordica charantia* Linn., and cucumber (Cucurbitaceae) were all abundant and heavily infested with *Tridacus pectoralis* Walk. From the first no parasites were obtained, but the second yielded a single specimen of a Dirhinus new to science and the third a single specimen of *Spalangia afra* Silv.

Pumpkin of undetermined species (Cucurbitaceae): Bought in the market; scarce. Infested with *Dacus brevistylus* Bez. from which were reared *Opius perproximus* Silv. and *Spalangia afra* Silv.

Kenya Colony

Nairobi and the highlands accessible from that town by rail were worked by Krauss between April 6 and June 23, 1936. Nairobi, particularly, proved a very rich source of useful fruits and berries of native and introduced species. Of these nearly one hundred species were examined, but only those from which flies or parasites were reared are given in the accompanying table.

A species of Strychnos, of the family Loganiaceae, not shown in the table, was the most productive source of fruit flies in Nairobi, and perhaps the most likely source of a useful parasite found during our whole expedition. This fruit is a small orange-colored drupe which is produced in great quantity on a medium sized

tree much used in Nairobi and its outskirts for shade and ornament. Showing a very high incidence of fly attack and a considerable percentage of parasitism the fruit provided a large number of parasitized pupae which we endeavoured to carry along with us on our return to the United States but which, due to the duration of the voyage and other circumstances, failed to survive. Had our expedition lasted longer, Strychnos would undoubtedly have provided additional material for air shipments of parasites which could have reached America in good shape, where earlier shipments made from Tanga had failed because of their necessarily small size and our own inexperience of the complexities of African communications. Unfortunately, however, our somewhat hurried departure from Nairobi took place two or three weeks before the height of the fruiting season of Strychnos and before parasites had begun to emerge in quantities sufficient for shipment.

The parasites found in Strychnos were *Opius perproximus modestor* Silv., *Opius fullawayi* Silv., Opius of undetermined species, (*Bracon*) *Microbracon celer* var., *Tetrastichus giffardianus* Silv., *Tetrastichus n. sp.* near *giffardii* Silv., and an Encyrtid of undetermined species. *Opius perproximus modestor* Silv. was the most abundant among the Braconidae and the new species of *Tetrastichus* near *giffardii* Silv. was by far predominant among the Chalcids. Most of our parasite material emerged during the first week on board our homeward-bound ship and all the parasites were reared from a single species of fly, *Ceratitis nigra* Graham. The percentage of parasitism by all the species was around 50 per cent, but the great quantity of our material and the difficulties of handling it in our crowded cabins prevented us from making accurate counts of the relative abundance of each species.

The table showing other fly-infested fruits of Kenya follows:

Date 1936	Locality	Fruit Host	Fly Species Reared	Parasites Reared
May 2	Meru	*Solanum naumanni* Engl. (Solanaceae)	*Ceratitis n. sp.*	None
May 3	Meru	Himalayan blackberry (Rosaceae)	*Ceratitis rubivora* Coq.	*Opius fullawayi* (Silv.)
			Ceratitis colae Silv.	Opius undetermined sp.
May 3	Nanyuki	*Coffea arabica* Linn. (Rubiaceae)	*Ceratitis capitata* Wied.	None
May 16	Kakamega	*Solanum* prob. *indicum* Linn. (Solanaceae)	*Ceratitis n. sp.*	*Opius fullawayi* (Silv.)
				Opius undetermined sp.
May 18	Kakamega and Londiani	*Melothria sp.* (Cucurbitaceae)	*Tridacus n. sp.* near *chrysomphalus*	None
May 16	Londiani	*Rubus sp.* (Rosaceae)	*Ceratitis rubivora* Coq.	None
May 20	Nanyuki	*Cissus nananquensis* (Ampelidaceae)	Undetermined Trypetid	None
April	Nairobi	*Acokanthera longiflora* Stapf. (Apocynaceae)	*Ceratitis capitata* Wied.	*Opius perproximus* Silv.
			Ceratitis cosyra Walker.	*Opius humilis* Silv.
			Cerat tis bremii Guer-Men.	*Tetrastichus giffardii* Silv.
April	Nairobi	Loquat	*Ceratitis capitata* Wied.	None
			Ceratitis colae Silv.	None
April	Nairobi	*Tacsonia sp.* (Passifloraceae)	*Ceratitis capitata* Wied.	None
April	Nairobi	*Duranta plumieri* Jacq. (Verbenaceae)	*Tridacus n. sp.*	*Opius fullawayi* (Silv.)
				Opius perproximus Silv.
April	Nairobi	*Dovyalis caffra* Warb. (Flacourtiaceae)	*Ceratitis capitata* Wied.	Miscogasteridae— genus near Halticopter
			Ceratitis colae Silv.	
April	Nairobi	*Podocarpus gracilior* Pilger (Podocarpaceae)	*Ceratitis colae* Silv.	None
April	Nairobi	*Warburgia ugandensis* Sprague (Canellaceae)	*Ceratitis cosyra* Walk.	*Opius perproximus* Silv.
April	Nairobi	*Rawsonia usambarensis* K. Schum. (Flacourtiaceae)	*Ceratitis colae* Silv.	None
			Ceratitis rubivora Coq.	None
April	Nairobi	*Solanum naumannii* Engl. (Solanaceae)	*Ceratitis n. sp.*	*Opius perproximus* Silv.
April	Nairobi	*Teclea trichocarpa* Engl. (Rutaceae)	*Ceratitis capitata* Wied.	*Opius humilis* Silv.
				Opius fullawayi (Silv.)
April	Nairobi	*Vangueria sp.* (Rubiaceae)	*Ceratitis capitata* Wied.	None
April	Nairobi	*Acokanthera schimperi* Schweinf. (Apocynaceae)	*Ceratitis bremii* Guer Men.	None
May and June	Nairobi	*Brucea antidysenterica* Miller (Simarubaceae)	*Ceratitis capitata* Wied.	*Opius fullawayi* (Silv.)
				Opius undetermined sp.
May	Nairobi	*Berberis holstii* Engl. (Berberidaceae)	*Ceratitis capitata* Wied.	None
May and June	Nairobi	*Momordica sp.* (Cucurbitaceae)	*Tridacus punctatifrons* Karsch.	None
May	Nairobi	*Deinbollia sp.* (Sapindaceae)	*Ceratitis rubivora* Coq.	Opius undetermined sp.
May	Nairobi	Himalayan blackberry (Rosaceae)	*Ceratitis rubivora* Coq.	None
June	Nairobi	*Coffea arabica* Linn. (Rubiaceae)	*Ceratitis capitata* Wied.	*Opius humilis* Silv.
June	Nairobi	*Melothria sp.* (Cucurbitaceae)	Dacinae undetermined sp.	None

Uganda

The Crown Colony of Uganda was visited by Bianchi from April 20 to June 2, 1936. Eight or nine days were spent in the Lake Victoria Region (Entebbe, Kampala, and Jinja) which from the first appeared but scantily provided with fruit; nearly three weeks were spent at the Busingiro Forest Station, about midway between Lakes Kyoga and Albert, on the arterial that connects East Africa with the Belgian Congo; the rest of the time was spent in a tour of the West Nile District of the Northern Province. The outskirts of Busingiro Forest; certain areas of the West Nile District which very roughly coincided with the western escarpment of the Nile River Basin; and the plains of Soroti proved the most bountiful sources of fruit in the Colony. Had time been available to return to these areas at a different season and more leisurely, it is probable that valuable results could have been obtained. As it was, however, the visit to Uganda seemed to be ill timed in relation to the fruiting seasons of many of the most likely looking available species of fruit.

The Shea butter tree, *Butyrospermum niloticum* Kotschy (Sapotaceae) proved one of the disappointments of the trip. Reported as a host of *Ceratitis giffardii* Bezzi in the French Sudan (Silvestri; an expedition to Africa in search of the natural enemies of fruit flies) it was to be expected that Butyrospermum would harbor the same or other fruit flies in Uganda. But although the fruit is to all appearances an ideal fruit-fly host and although it could be collected fully matured and in great quantities in several localities of the West Nile District, no sign of fly attack was ever seen on it.

Tamarind trees, *Tamarindus indica* Linn. (Caesalpiniaceae), were a very common and conspicuous part of the flora in certain areas near Pakwach, West Nile District, and although the height of the fruiting season was past some fruit remained on them. None of this proved infested, however, although on one occasion a Ceratitis was seen resting on the foliage of a tree.

Out of a long list of potential hosts only the following fruits yielded either flies or parasites:

Chrysophyllum albidum Don. (Sapotaceae): Tall, fringe-of-the-forest tree with brown, semi-edible fruits about the size of a small apple. Only a few specimens collected on the outskirts of Busingiro Forest. Showed a small incidence of attack by *Ceratitis colae* Silv. and *Ceratitis punctata* Wied. and produced a single specimen of an Opius new to science and two specimens of Cynipideae of the genus Ganaspis.

Solanum naumannii Engl. (Solanaceae): Found only on the edge of Busingiro Forest, seemingly at the end of the fruiting season. Ten pounds of the fruit, a small berry, showed almost a 100 per cent incidence of attack by a Ceratitis new to science but yielded only 21 specimens of *Tetrastichus* probably *oxyurus* Silv., and only four specimens of *Opius fullawayi* (Silv.).

Psidium guajava Linn. (Myrtaceae): Found mostly scattered among bush of uncultivated areas near Kampala, Jinja, and Busingiro, but not seen east of the latter point. In Busingiro this fruit was attacked by *Ceratitis colae* Silv. and *Ceratitis rubivora* Coq. but produced no parasites.

Eugenia jambos Linn. (Myrtaceae): Common rose apple. From the fruit of cultivated trees in Busingiro were reared specimens of *Ceratitis colae* Silv. but no parasites.

Persea gratissima Gaertn. (Lauraceae): Avocado; a light green, moderately thin-skinned variety was found unusually abundant in the town of Jinja growing on a small tree evidently planted for ornamental purposes along the streets and in gardens, but this variety showed no attack by fly. From a single specimen of a thicker skinned and much scarcer variety found in Busingiro were bred a few *Ceratitis rubivora* Coq. but no parasites.

Myrianthus arboreus Beauv. (Moraceae): More abundant in Busingiro than in Amani, Tanganyika, but evidently not as heavily attacked by fly. Yielded *Ceratitis colae* Silv. but no parasites.

Vitex either *madiensis* Oliv. or *schweinfurthii* Bak. (Verbenaceae): Semi-edible, olive-like, growing on bushy trees up to ten feet in height. Moderately abundant in several places on the west escarpment of the Nile River Basin. Five pounds collected near Amugo, West Nile District, yielded ten specimens of *Tridacus pectoralis* Walk. but no parasites.

Capparis erythrocarpa Isert. (Capparidaceae): A very thorny rambler with a red fruit similar in size and structure to a small granadilla. Moderately abundant in several places both east and west of the Nile. More than 100 fruits collected near Soroti, Northern Province, yielded about 40 specimens of *Themarictera laticeps* Loew. but no parasites.

Some Important Factors to Consider in Selecting Seedlings

By Raymond K. Conant

The program of raising, selecting, and testing of new varieties of sugar cane will probably be carried on as long as the cane sugar industry continues to exist, for the reason that we will never be satisfied with the varieties we have, and will persist in our endeavor to find canes which will improve our yields and reduce our costs.

The raising of new varieties is not difficult today, since we have at our disposal the knowledge gained from scientific research, which has developed the technique of cane breeding to a point where this part of the program is comparatively easy. Selecting the best of these new varieties, and deciding which ones will prove most profitable to the plantations, is still another matter. Herein lies the difficulty. The question of what factors should be considered foremost in variety selection is one which deserves a great deal of study. We know what qualities we want in our seedlings, but these qualities never seem to be combined in one variety. In other words, we find both good and poor qualities in all of our varieties, and the question of what qualities we should emphasize as being of foremost importance is one which is open to debate. The fieldmen want disease-resistant varieties that grow fast, close-in early, ratoon well, hold-over, and are easy to harvest. The millmen want canes with excellent juices, and a minimum of trash. Their varieties must be easy to crush, and must have juices that clarify, and boil properly. Proper fiber content, and other minor qualifications are desirable in varieties from the millman's point of view.

Disease resistant varieties that close-in fast and ratoon well are not difficult to find now, since many of the new varieties carry enough of *Saccharum sinense, Saccharum spontaneum,* or *Saccharum robustum* blood to insure great vegetative vigor and disease resistance. But a great many of these canes have rather poor juice quality, or are hard to harvest because of small stalks and their tendency to be trashy. These canes are usually looked upon with great favor by fieldmen up until harvesting operations commence. The difficulties that are often encountered in harvesting and milling these canes cause both fieldmen and millmen to be apprehensive of the value of these varieties, and the claim is often made that what labor and money is saved in cultivation by these fast-growing, rapid closing-in canes is lost because of increased labor requirements in harvesting, and added transportation and milling expense.

If we look at this problem from the fieldman's viewpoint, we may be inclined to discount juice quality, and place emphasis on yields and labor requirements for cultivation, and the amount of labor required for harvesting. The millman may see the problem only from the standpoint of juice and milling qualities, and may disregard the question of cultivation. He may consider increased yields to be of no value if these increases are accompanied by poor juice, poor milling qualities, etc.

Briefly, then, the type of canes that we all want must have the following qualifications:

1. Disease resistance.
2. Great vegetative vigor:
   (a) good germination from seed;
   (b) good ratooning;
   (c) good closing-in.
3. Good cane yields.
4. Reasonably easy to harvest.
5. Good juice.
6. Minimum trash.
7. Good milling, including all of the ramifications.

Preliminary selection work is based almost entirely on appearances. We look for healthy-appearing canes with great vegetative vigor, and often consider stalk size of secondary importance. After we have spread the outstanding varieties from the preliminary selection to a point where sufficient seed is available, it is customary to plant these canes in variety tests which usually have 5 or more replications in comparison with some standard cane of known reputation. Observational notes are taken during the progress of the experiments, regarding vegetative vigor, health, etc., and when the tests are harvested at maturity careful data are obtained in regard to cane yields, juices, and sugar yields. Observational notes are taken at this time relative to weed suppression, holding-over qualities, disease resistance, insect damage, stalk size, etc., but stalk size may be only casually mentioned if cane and sugar yields are good.

By the time that the replicated or "Grade A" tests are harvested, we have a fair idea regarding disease resistance, vegetative vigor, yields, juices, and trash, but we have very little information on the harvesting qualities of the varieties in the tests, and know practically nothing regarding the milling qualities of the varieties.

That the latter two qualities are of the utmost importance cannot be denied, but ways and means of determining or measuring the importance of these two factors are not at our disposal until the varieties are planted to field-scale proportions, and even after we have the varieties in field plantings it is sometimes difficult to determine just how or to what extent these two factors affect our costs.

After a variety has been planted to and harvested from 50 acres or more, sufficient data should be available relative to cultivation, harvesting, and transportation costs, and enough knowledge regarding the milling should be at hand to enable one to calculate with some degree of accuracy the actual value of the variety in question. With this in mind, the writer has prepared four tables relevant to labor requirements and costs that may be involved with these 4 operations when quality ratios vary from 6 to 14 and when cane yields vary from 50 to 100 tons per acre.

The data in these tables should not be construed as being representative of labor requirements and costs for any particular plantation. They were prepared for this report merely for the purpose of serving as a basis upon which certain hypothetical problems could be discussed, pertinent to the variety question in *wet, unirrigated* districts where weed control is a major problem, and burning before harvesting can seldom if ever be done. However, the tables are flexible enough to take care of a

variety of conditions, and it is possible that they might be applicable to seedling problems identified with other conditions.

The tables used in this report pertain, for the sake of simplicity, to a crop of 10,000 tons of sugar.

Assume now that a 50-acre field of variety "A" has been harvested, and the following data relative to this variety have been obtained:

1. Cultivation—15 men per acre.
2. Cane yield—90 tons per acre net.
3. Q. R.—11.
4. Harvesting rather difficult:
   (a) Cutters average—5 net tons cane per man.
   (b) Loaders average—11.5 net tons cane per man.
   (c) Increased rates given cutters and loaders.
5. Tare—14 per cent.
6. Transportation costs higher than average due to trash and added cane.
7. Milling—considered poor, because of trash and poor juice.

Data from fields in the standard variety "X" supply the following information:

1. Cultivation—30 men per acre.
2. Cane yields—60 tons per acre net.
3. Q. R.—9.
4. Harvesting:
   (a) Cutters average 7.5 tons net cane per man.
   (b) Loaders average 15 tons net cane per man.
5. Tare—8 per cent.

The above information tells us that we are saving 15 men per acre in cultivation with variety "A," that we are getting more cane and more sugar per acre from variety "A," despite poorer juices, but it also tells us that we are using more men for harvesting, and are increasing our transportation and milling costs due to poor juice and increased trash with variety "A." The problem, then, is to determine whether the saving in cultivation, and the increased yields will offset the increased harvesting, transportation, and milling costs.

Example 1:

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	11	9
TC/A	90	60
TS/A	8.18	6.66
Tare, Per Cent	14	8
Harvesting:		
TC per man cut and load	3.5	5.0
TS per man cut and load	.31818	.5555
Delivery cost per ton of cane	$1.40	$1.30
Manufacturing cost per ton of sugar	$2.14	$1.65

The above data will be explained as we go along.

Turn first to *Table I—Cultivation* and obtain the following:

	Variety "A"	Variety "X"
TC/A	90	60
Q. R.	11	9
M/A	15	30
Ac's/10,000 TS	1,222	1,500
M/10,000 TS	18,330	45,000
Cost per 10,000 TS at $1.50 per man	$27,495	$67.500

Before turning to Table II, a brief explanation will be given of the term TC/M (tons of cane per man cutting and loading, or cutting and packing where cane is transported by flumes) as used in this paper.

Variety "A"—1 man cuts 5 tons net cane per day
1 man loads 11.5 tons net cane per day

or 2.3 men cut 11.5 tons net cane per day
1 man loads 11.5 tons net cane per day

so 3.3 men cut and load 11.5 tons net cane per day
or 1 man cuts and loads 3.5 tons net cane per day

Variety "X"—1 man cuts 7.5 tons net cane per day
1 man loads 15 tons net cane per day

or 2 men cut 15 tons net cane per day
1 man loads 15 tons net cane per day

so 3 men cut and load 15 tons net cane per day
or 1 man cuts and loads 5 tons net cane per day

For simplicity, the cutting and loading will be considered hereafter in this paper as one operation, and any reference to tons of cane per man in the harvesting, should be interpreted as tons of cane per man cutting and loading. This figure can be obtained as illustrated above.

Now we refer to *Table II—Harvesting*, and find the following:

	Variety "A"	Variety "X"
TC/M	3.5	5
Q. R.	11	9
TS/M	.31818	.5555
TC/A	90	60
TS/A	8.18	6.66
M/10,000 TS	31,429	18,000
Ac's/10,000 TS	1,222	1,500
TC/10,000 TS	110,000	90,000

Table III—Transportation, Cutting and Loading Costs:

Assume that it costs $1.30 per ton of cane for delivery at the mill for standard variety "X," and that because of more difficult cutting and loading we have to pay the cutters 5 cents more per ton of cane for cutting variety "A," and the loaders 4 cents more per ton of cane for loading variety "A," and that due to trash, etc., it

costs 1 cent more per ton of cane to transport variety "A." Then we have \$1.30 per ton of cane to deliver variety "X" and \$1.40 per ton of cane to deliver variety "A."

	Variety "A"	Variety "X"
Q. R.	11	9
TC/10,000 TS	110,000	90,000
Cost of delivery per ton of cane	\$ 1.40	\$ 1.30
Cost of delivery per 10,000 TS	\$154,000	\$117,000

Table IV—Manufacturing:

	Variety "A"	Variety "X"
Q. R.	11	9
Tare	14%	8%
Cost per ton of sugar	\$ 2.14	\$ 1.65
Cost per 10,000 TS	\$21,400	\$16,500

Combining the data obtained from the four tables we get:

	Variety "A"	Variety "X"
Cultivation	\$ 27,495	\$ 67,500
Harvesting and transportation or delivery	154,000	117,000
Manufacturing	21,400	16,500
	\$202,895	\$201,000
	— 201,000	
	\$ 1,895	

(19 cents per ton of sugar against variety "A")

In regard to labor we find from Tables I and II:

	Variety "A"	Variety "X"
Cultivation	18,330 men per 10,000 TS	45,000 men per 10,000 TS
Harvesting	31,429 men per 10,000 TS	18,000 men per 10,000 TS
Total	49,759 men per 10,000 TS	63,000 men per 10,000 TS
		—49,759
		13,241

(13,241 man-days saved in favor of variety "A.")

So we have a cost of 19 cents per ton of sugar against variety "A," but a substantial saving in labor in favor of variety "A."

Example 2:

If the Q. R. of variety "A" were 13 instead of 11, we would find the following from the tables:

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	13	9
TC/A	90	60
TS/A	6.92	6.66
Tare, Per Cent	14	8
Harvesting:		
TC/M	3.5	5.0
TS/M	.2692	.5555
Delivery cost per ton cane	\$1.40	\$1.30
Manufacturing per ton sugar	\$2.14	\$1.65

	Variety "A" Men	Variety "A" Dollars	Variety "X" Men	Variety "X" Dollars
Cultivation	21,660	32,490	45,000	67,500
Harvesting	37,147	.....	18,000	.....
Delivering	.....	182,000	....	117,000
Manufacturing	.....	25,300	.....	16,500
	58,807	$239,790	63,000	$201,000
		—201,000	—58,807	
		$ 38,790	4,193	

($3.88 per ton of sugar against variety "A" and a saving of only 4,193 man-days in favor of variety "A" with Q. R. of 13.)

Example 3:

Assume that variety "A" has Q. R. of 11 against 9 for "X," and that cultivation requirements are 15 men per acre for "A" and 30 men per acre for "X," and that "A" has large stalks and can be harvested as cheaply, and as easily per ton of cane as "X," but that due to "A" having poorer juice than "X," manufacturing costs are slightly higher for "A." Tare 8 per cent for both varieties.

Referring to the tables we find:

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	11	9
TC/A	90	60
TS/A	8.18	6.66
Tare, Per Cent	8	8
Harvesting:		
TC/M	5.0	5.0
TS/M	.45454	.5555
Delivery cost per ton cane	$1.30	$1.30
Manufacturing per ton sugar	$2.03	$1.65

	Variety "A" Men	Variety "A" Dollars	Variety "X" Men	Variety "X" Dollars
Cultivation	18,330	27,495	45,000	67,500
Harvesting	22,000	.....	18,000	.....
Delivering	.....	143,000	.....	117,000
Manufacturing	.....	20,300	.....	16,500
	40,330	$190,795	63,000	$201,000
			—40,330	—190,795
			22,670	$ 10,205

($1.02 per ton of sugar in favor of variety "A" and 22,670 man-days in favor of variety "A.")

Example 4:

Same as Example 3 with the exception that the Q. R. of "A" is 13.

	Variety "A"	Variety "X"
Cultivation: Men per acre	15	30
Q. R.	13	9
TC/A	90	60
TS/A	6.92	6.66
Tare, Per Cent	8	8

Harvesting:		
TC/M	5.0	5.0
TS/M	.3846	.5555
Delivery cost per ton cane	$1.30	$1.30
Manufacturing per ton sugar	$2.38	$1.65

	Variety "A"		Variety "X"	
	Men	Dollars	Men	Dollars
Cultivation	21,660	32,490	45,000	67,500
Harvesting	26,000	.....	18,000	.....
Delivering	.....	169,000	.....	117,000
Manufacturing	.....	23,800	.....	16,500
	47,660	$225,290	63,000	$201,000
		—201,000	—47,660	
		$ 24,290	15,340	

($2.43 per ton of sugar against variety "A" and 15,340 man-days in favor of variety "A.")

Example 5:

Assume that variety "B" has excellent juice, but is slow in closing-in, and is a poor ratooner. Q. R. of "B" = 7 and "C" = 9. Cultivation requirements 40 men per acre for "B" and 20 men per acre for "C." Tons cane per man cutting and loading = 5 for both varieties, and tare = 8 per cent for both varieties. Delivery costs $1.30 per ton of cane for both varieties. Cane yields 50 TC/A for "B" and 60 TC/A for "C."

	Variety "B"	Variety "C"
Cultivation: Men per acre	40	20
Q. R.	7	9
TC/A	50	60
TS/A	7.14	6.66
Tare, per cent	8	8
Harvesting:		
TC/M	5.0	5.0
TS/M	.71428	.5555
Delivery cost per ton cane	$1.30	$1.30
Manufacturing per ton sugar	$1.28	$1.65

	Variety "B"		Variety "C"	
	Men	Dollars	Men	Dollars
Cultivation	56,000	84,000	30,000	45,000
Harvesting	14,000	.....	18,000	.....
Delivering	.....	91,000	.....	117,000
Manufacturing	.....	12,800	.....	16,500
	70,000	$187,800	48,000	$178,500
	—48,000	—178,500		
	22,000	$ 9,300		

(93 cents per ton of sugar and 22,000 man-days against variety "B.")

Examples similar to those given above could be cited without end, but the purpose here is to bring out certain factors that are of importance in seedling selection work. It will be noted that juice, or Q. R. as we have considered it in this paper,

enters every phase of the problem as considered, i. e., Q. R. affects cultivation costs and labor requirements for cultivating, indirectly, through the effect on area; it affects harvesting through the *tons of sugar cut and loaded per man;* it affects transportation through the amount of cane to be handled to produce a given amount of sugar, and it affects manufacturing in the same way.

Vegetative vigor affects cultivation requirements, yield, and consequently area; and size of stalk affects harvesting directly, and transportation and manufacturing indirectly through tare and weight per unit of volume. That is, we would expect a large-stalk cane to have less trash, and weigh more per unit of volume than a small-stalk variety.

Yield of cane would naturally affect all four phases, but the effect of yield of cane is dependent upon Q. R.

Since cane yields are associated with vegetative vigor, it would seem that these two qualities could be considered together, but Q. R. and size of stalk may be considered separately or together. That is, poor juices can be excused to some extent in a large-stalk cane, but in a small-stalk cane that is difficult to harvest, poor juices may increase costs even where a saving is made in cultivation.

Since the purpose of raising sugar cane is to produce sugar, it goes without saying that juice is a very important factor to consider in variety selection work, but the data in Example 3 indicate that a poor-juice cane may be profitable to raise providing it has great vegetative vigor, and has large stalks, so that the harvesting of it is reasonably easy; and providing also that the transportation system and factory can handle the added cane needed to produce a given amount of sugar; and vice versa, a good-juice cane (Example 5), that may be expensive to cultivate, may not be as profitable to raise as a poorer-juice cane that may be reasonably cheap to cultivate.

Note:

The data on costs used in this paper do not take into account such items as repairs, depreciation, rentals, etc., so that the figures are somewhat lower than the actual costs involved in the four operations considered. It was felt that in order to be clear, the tables and data would need to be as simple as possible, so in order to avoid confusion no attempt was made to have the data include all of the expenses incidental to actual conditions. However, since most of the items not included are fixed charges, the operating costs used in the tables should be sufficient for the purpose we have in mind.

The data on cultivation requirements are supposed to be applicable to ratoon fields only.

TABLE I

MAN-DAYS REQUIRED TO CULTIVATE AN AREA SUFFICIENT TO PRODUCE 10,000 TONS OF SUGAR

TC/A	Q. R.	TS/A	Ac's Per 10,000 TS	Total Man-Days At 5 M/A	10 M/A	15 M/A	20 M/A	25 M/A	30 M/A	35 M/A	40 M/A	45 M/A	50 M/A
50	6	8.33	1,200	6,000	12,000	18,000	24,000	30,000	36,000	42,000	48,000	54,000	60,000
50	7	7.14	1,400	7,000	14,000	21,000	28,000	35,000	42,000	49,000	56,000	63,000	70,000
50	8	6.25	1,600	8,000	16,000	24,000	32,000	40,000	48,000	56,000	64,000	72,000	80,000
50	9	5.55	1,800	9,000	18,000	27,000	36,000	45,000	54,000	63,000	72,000	81,000	90,000
50	10	5.00	2,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000
50	11	4.54	2,200	11,000	22,000	33,000	44,000	55,000	66,000	77,000	88,000	99,000	110,000
50	12	4.16	2,400	12,000	24,000	36,000	48,000	60,000	72,000	84,000	96,000	108,000	120,000
50	13	3.846	2,600	13,000	26,000	39,000	52,000	65,000	78,000	91,000	104,000	117,000	130,000
50	14	3.57	2,800	14,000	28,000	42,000	56,000	70,000	84,000	98,000	112,000	126,000	140,000
60	6	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
60	7	8.57	1,167	5,835	11,670	17,505	23,340	29,175	35,010	40,845	46,680	52,515	58,350
60	8	7.50	1,333	6,665	13,330	19,995	26,660	33,325	39,990	46,665	53,320	59,985	66,650
60	9	6.66	1,500	7,500	15,000	22,500	30,000	37,500	45,000	52,500	60,000	67,500	75,000
60	10	6.00	1,667	8,335	16,670	25,005	33,340	41,675	50,010	58,345	66,680	75,015	83,350
60	11	5.45	1,833	9,165	18,333	27,495	36,660	45,825	54,990	64,155	73,320	82,485	91,650
60	12	5.00	2,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000
60	13	4.615	2,167	10,835	21,670	32,505	43,340	54,175	65,010	75,845	86,680	97,515	108,350
60	14	4.28	2,333	11,665	23,330	34,995	46,660	58,325	69,990	81,665	93,320	104,985	116,650
70	6	11.66	857	4,285	8,570	12,855	17,140	21,425	25,710	29,995	34,280	38,565	42,850
70	7	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
70	8	8.75	1,143	5,715	11,430	17,145	22,860	28,575	34,290	40,005	45,720	51,435	57,150
70	9	7.77	1,286	6,430	12,860	19,290	25,720	32,150	38,580	45,010	51,440	57,870	64,300
70	10	7.00	1,429	7,145	14,290	21,435	28,580	35,725	42,870	50,015	57,160	64,305	71,450
70	11	6.36	1,571	7,855	15,710	23,565	31,420	39,275	47,130	54,985	62,840	70,695	78,550
70	12	5.83	1,714	8,570	17,140	25,710	34,280	42,850	51,420	59,990	68,560	77,130	85,700
70	13	5.38	1,857	9,285	18,570	27,855	37,140	46,425	55,710	64,995	74,280	83,565	92,850
70	14	5.00	2,000	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000

TC/A	Q. R.	TS/A	Ac's Per 10,000 TS	Total Man-Days At 5 M/A	10 M/A	15 M/A	20 M/A	25 M/A	30 M/A	35 M/A	40 M/A	45 M/A	50 M/A
80	6	13.33	750	3,750	7,500	11,250	15,000	18,750	22,500	26,250	30,000	33,750	37,500
80	7	11.428	875	4,375	8,750	13,125	17,500	21,875	26,250	30,625	35,000	39,375	43,750
80	8	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
80	9	8.888	1,125	5,625	11,250	16,875	22,500	28,125	33,750	39,375	45,000	50,625	56,250
80	10	8.00	1,250	6,250	12,500	18,750	25,000	31,250	37,500	43,750	50,000	56,250	62,500
80	11	7.27	1,375	6,875	13,750	20,625	27,500	34,375	41,250	48,125	55,000	61,875	68,750
80	12	6.66	1,500	7,500	15,000	22,500	30,000	37,500	45,000	52,500	60,000	67,500	75,000
80	13	6.15	1,625	8,125	16,250	24,375	32,500	40,625	48,750	56,875	65,000	73,125	81,250
80	14	5.71	1,750	8,750	17,500	26,250	35,000	43,750	52,500	61,250	70,000	78,750	87,500
90	6	15.00	667	3,335	6,670	10,005	13,340	16,675	20,010	23,345	26,680	30,015	33,350
90	7	12.85	778	3,890	7,780	11,670	15,560	19,450	23,340	27,230	31,120	35,010	38,900
90	8	11.25	889	4,445	8,890	13,335	17,780	22,225	26,670	31,115	35,560	40,005	44,450
90	9	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
90	10	9.00	1,111	5,555	11,110	16,665	22,220	27,775	33,330	38,885	44,440	49,995	55,550
90	11	8.18	1,222	6,110	12,220	18,330	24,440	30,550	36,660	42,770	48,880	54,990	61,100
90	12	7.50	1,333	6,665	13,330	19,995	26,660	33,325	39,990	46,665	53,320	59,985	66,650
90	13	6.92	1,444	7,220	14,440	21,660	28,880	36,100	43,320	50,540	57,760	64,980	72,200
90	14	6.428	1,555	7,775	15,550	23,325	31,100	38,875	46,650	54,425	62,200	69,975	77,750
100	6	16.66	600	3,000	6,000	9,000	12,000	15,000	18,000	21,000	24,000	27,000	30,000
100	7	14.285	700	3,500	7,000	10,500	14,000	17,500	21,000	24,500	28,000	31,500	35,000
100	8	12.50	800	4,000	8,000	12,000	16,000	20,000	24,000	28,000	32,000	36,000	40,000
100	9	11.11	900	4,500	9,000	13,500	18,000	22,500	27,000	31,500	36,000	40,500	45,000
100	10	10.00	1,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	50,000
100	11	9.09	1,100	5,500	11,000	16,500	22,000	27,500	33,000	38,500	44,000	49,500	55,000
100	12	8.33	1,200	6,000	12,000	18,000	24,000	30,000	36,000	42,000	48,000	54,000	60,000
100	13	7.69	1,300	6,500	13,000	19,500	26,000	32,500	39,000	45,500	52,000	58,500	65,000
100	14	7.14	1,400	7,000	14,000	21,000	28,000	35,000	42,000	49,000	56,000	63,000	70,000

Operations to include: Replanting, palipaliing, weeding, spraying, cultivating, and applying fertilizer, but not cost of fertilizer.
Rate of pay in this paper considered at $1.50 per man-day.

TABLE II

MAN-DAY REQUIREMENTS FOR HARVESTING 10,0000 TONS OF SUGAR
(Cutting and Loading Only)

					50 TC/A			60 TC/A			70 TC/A			80 TC/A			90 TC/A			100 TC/A		
TC/M	Q. R.	TS/M	Men Per 10,000 TS	TC Per 10,000 TS	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A	Ac's Per 10,000 TS	M/A	TS/A
3	6	.5000	20,000	60,000	1,200	16.6	8.33	1,000	20	10.00	857	23.3	11.66	750	26.6	13.33	667	30	15.00	600	33.3	16.66
3	7	.42857	23,333	70,000	1,400	16.6	7.14	1,167	20	8.57	1,000	23.3	10.00	875	26.6	11.428	778	30	12.857	700	33.3	14.285
3	8	.3750	26,666	80,000	1,600	16.6	6.25	1,333	20	7.50	1,143	23.3	8.75	1,000	26.6	10.00	889	30	11.25	800	33.3	12.50
3	9	.3333	30,000	90,000	1,800	16.6	5.55	1,500	20	6.66	1,286	23.3	7.77	1,125	26.6	8.888	1,000	30	10.00	900	33.3	11.11
3	10	.3000	33,333	100,000	2,000	16.6	5.00	1,667	20	6.00	1,429	23.3	7.00	1,250	26.6	8.00	1,111	30	9.00	1,000	33.3	10.00
3	11	.2727	36,666	110,000	2,200	16.6	4.54	1,833	20	5.45	1,571	23.3	6.36	1,375	26.6	7.27	1,222	30	8.18	1,100	33.3	9.09
3	12	.2500	40,000	120,000	2,400	16.6	4.16	2,000	20	5.00	1,714	23.3	5.83	1,500	26.6	6.66	1,333	30	7.50	1,200	33.3	8.33
3	13	.23077	43,333	130,000	2,600	16.6	3.846	2,167	20	4.615	1,857	23.3	5.38	1,625	26.6	6.15	1,444	30	6.92	1,300	33.3	7.69
3	14	.21428	46,666	140,000	2,800	16.6	3.57	2,333	20	4.28	2,000	23.3	5.00	1,750	26.6	5.71	1,555	30	6.428	1,400	33.3	7.14
3.5	6	.5833	17,144	60,000	1,200	14.3	8.33	1,000	17.1	10.00	857	20	11.66	750	22.8	13.33	667	25.7	15.00	600	28.6	16.66
3.5	7	.5000	20,000	70,000	1,400	14.3	7.14	1,167	17.1	8.57	1,000	20	10.00	875	22.8	11.428	778	25.7	12.857	700	28.6	14.285
3.5	8	.4375	22,857	80,000	1,600	14.3	6.25	1,333	17.1	7.50	1,143	20	8.75	1,000	22.8	10.00	889	25.7	11.25	800	28.6	12.50
3.5	9	.38889	25,713	90,000	1,800	14.3	5.55	1,500	17.1	6.66	1,286	20	7.77	1,125	22.8	8.888	1,000	25.7	10.00	900	28.6	11.11
3.5	10	.3500	28,571	100,000	2,000	14.3	5.00	1,667	17.1	6.00	1,429	20	7.00	1,250	22.8	8.00	1,111	25.7	9.00	1,000	28.6	10.00
3.5	11	.31818	31,429	110,000	2,200	14.3	4.54	1,833	17.1	5.45	1,571	20	6.36	1,375	22.8	7.27	1,222	25.7	8.18	1,100	28.6	9.09
3.5	12	.29166	34,286	120,000	2,400	14.3	4.16	2,000	17.1	5.00	1,714	20	5.83	1,500	22.8	6.66	1,333	25.7	7.50	1,200	28.6	8.33
3.5	13	.2692	37,147	130,000	2,600	14.3	3.846	2,167	17.1	4.615	1,857	20	5.38	1,625	22.8	6.15	1,444	25.7	6.92	1,300	28.6	7.69
3.5	14	.2500	40,000	140,000	2,800	14.3	3.57	2,333	17.1	4.28	2,000	20	5.00	1,750	22.8	5.71	1,555	25.7	6.428	1,400	28.6	7.14
4	6	.6666	15,000	60,000	1,200	12.5	8.33	1,000	15	10.00	857	17.5	11.66	750	20	13.33	667	22.5	15.00	600	25	16.66
4	7	.5714	17,500	70,000	1,400	12.5	7.14	1,167	15	8.57	1,000	17.5	10.00	875	20	11.428	778	22.5	12.857	700	25	14.285
4	8	.5000	20,000	80,000	1,600	12.5	6.25	1,333	15	7.50	1,143	17.5	8.75	1,000	20	10.00	889	22.5	11.25	800	25	12.50
4	9	.4444	22,500	90,000	1,800	12.5	5.55	1,500	15	6.66	1,286	17.5	7.77	1,125	20	8.888	1,000	22.5	10.00	900	25	11.11
4	10	.4000	25,000	100,000	2,000	12.5	5.00	1,667	15	6.00	1,429	17.5	7.00	1,250	20	8.00	1,111	22.5	9.00	1,000	25	10.00
4	11	.3636	27,500	110,000	2,200	12.5	4.54	1,833	15	5.45	1,571	17.5	6.36	1,375	20	7.27	1,222	22.5	8.18	1,100	25	9.09
4	12	.3333	30,000	120,000	2,400	12.5	4.16	2,000	15	5.00	1,714	17.5	5.83	1,500	20	6.66	1,333	22.5	7.50	1,200	25	8.33
4	13	.30769	32,500	130,000	2,600	12.5	3.846	2,167	15	4.615	1,857	17.5	5.38	1,625	20	6.15	1,444	22.5	6.92	1,300	25	7.69
4	14	.2857	35,000	140,000	2,800	12.5	3.57	2,333	15	4.28	2,000	17.5	5.00	1,750	20	5.71	1,555	22.5	6.428	1,400	25	7.14
5	6	.8333	12,000	60,000	1,200	10	8.33	1,000	12	10.00	857	14	11.66	750	16	13.33	667	18	15.00	600	20	16.66
5	7	.71428	14,000	70,000	1,400	10	7.14	1,167	12	8.57	1,000	14	10.00	875	16	11.428	778	18	12.857	700	20	14.285
5	8	.6250	16,000	80,000	1,600	10	6.25	1,333	12	7.50	1,143	14	8.75	1,000	16	10.00	889	18	11.25	800	20	12.50
5	9	.5555	18,000	90,000	1,800	10	5.55	1,500	12	6.66	1,286	14	7.77	1,125	16	8.888	1,000	18	10.00	900	20	11.11
5	10	.5000	20,000	100,000	2,000	10	5.00	1,667	12	6.00	1,429	14	7.00	1,250	16	8.00	1,111	18	9.00	1,000	20	10.00
5	11	.45454	22,000	110,000	2,200	10	4.54	1,833	12	5.45	1,571	14	6.36	1,375	16	7.27	1,222	18	8.18	1,100	20	9.09
5	12	.41666	24,000	120,000	2,400	10	4.16	2,000	12	5.00	1,714	14	5.83	1,500	16	6.66	1,333	18	7.50	1,200	20	8.33
5	13	.3846	26,000	130,000	2,600	10	3.846	2,167	12	4.615	1,857	14	5.38	1,625	16	6.15	1,444	18	6.92	1,300	20	7.69
5	14	.3571	28,000	140,000	2,800	10	3.57	2,333	12	4.28	2,000	14	5.00	1,750	16	5.71	1,555	18	6.428	1,400	20	7.14

Symbols:

TC/M = Tons net cane per man cut and load or cut and pack.
Q. R. = Quality ratio.
TS/M = Tons sugar per man cut and load or cut and pack.
Ac's = Acres.
M/A = Men per acre.
TS = Tons sugar.
TS/A = Tons sugar per acre.
TC/A = Tons cane per acre.

$$TS/M = \frac{TC/M}{Q.\ R.}$$

$$\text{Men per 10,000 TS} = \frac{10{,}000\ TS}{TS/M}$$

$$\text{Ac's per 10,000 TS} = \frac{10{,}000\ TS}{TS/A}$$

TC/M—Example: 1 man cuts 7.5 tons net cane
1 man loads 15 tons net cane
or 2 men cut 15 tons net cane
1 man loads 15 tons net cane

3 men cut and load 15 tons net cane
or 1 man cuts and loads 5 tons net cane

TABLE III

DELIVERY COSTS PER TON NET CANE AND DELIVERY COSTS PER 10,000 TONS OF SUGAR

Q. R.	TC Per 10,000 TS	$ .80	$ .90	$1.00	$1.10	$1.20	$1.30	$1.40	$1.50	$1.60	$1.70
6	60,000	$ 48,000	$ 54,000	$ 60,000	$ 66,000	$ 72,000	$ 78,000	$ 84,000	$ 90,000	$ 96,000	$102,000
7	70,000	56,000	63,000	70,000	77,000	84,000	91,000	98,000	105,000	112,000	119,000
8	80,000	64,000	72,000	80,000	88,000	96,000	104,000	112,000	120,000	128,000	136,000
9	90,000	72,000	81,000	90,000	99,000	108,000	117,000	126,000	135,000	144,000	153,000
10	100,000	80,000	90,000	100,000	110,000	120,000	130,000	140,000	150,000	160,000	170,000
11	110,000	88,000	99,000	110,000	121,000	132,000	143,000	154,000	165,000	176,000	187,000
12	120,000	96,000	108,000	120,000	132,000	144,000	156,000	168,000	180,000	192,000	204,000
13	130,000	104,000	117,000	130,000	143,000	156,000	169,000	182,000	195,000	208,000	221,000
14	140,000	112,000	126,000	140,000	154,000	168,000	182,000	196,000	210,000	224,000	238,000

Note: Delivery costs to include such operations as cutting and loading or cutting and packing, installing portable tracks or flumes, etc., as well as transportation.

TABLE IV

MANUFACTURING COSTS PER TON OF SUGAR AND MANUFACTURING COSTS PER 10,000 TONS OF SUGAR

	8 Per Cent Trash		10 Per Cent Trash		12 Per Cent Trash		14 Per Cent Trash		16 Per Cent Trash		18 Per Cent Trash	
Q. R.	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS	Cost Per TS	Cost Per 10,000 TS
6	$1.10	$11,000	$1.12	$11,200	$1.14	$11,400	$1.17	$11,700	$1.19	$11,900	$1.21	$12,100
7	1.28	12,800	1.31	13,100	1.33	13,300	1.36	13,600	1.39	13,900	1.41	14,100
8	1.46	14,600	1.49	14,900	1.53	15,300	1.55	15,500	1.58	15,800	1.61	16,100
9	1.65	16,500	1.68	16,800	1.72	17,200	1.75	17,500	1.78	17,800	1.81	18,100
10	1.83	18,300	1.87	18,700	1.91	19,100	1.95	19,500	1.98	19,800	2.02	20,200
11	2.03	20,300	2.06	20,600	2.10	21,000	2.14	21,400	2.18	21,800	2.22	22,200
12	2.20	22,000	2.24	22,400	2.29	22,900	2.33	23,300	2.38	23,800	2.42	24,200
13	2.38	23,800	2.43	24,300	2.48	24,800	2.53	25,300	2.57	25,700	2.62	26,200
14	2.57	25,700	2.62	26,200	2.67	26,700	2.72	27,200	2.77	27,700	2.82	28,200

Above data obtained as follows:

Factory handles 90 tons of net cane per hour or 97.82 tons of gross cane per hour with 8 per cent trash.

24 hours × 90 = 2,160 net tons cane per day.
Q. R. 10 = 216 tons of sugar per day.
Q. R. 12 = 180 tons of sugar per day.

Assume operating costs of factory = $396 per day.

$\frac{\$396}{216\ TS}$ = $1.83 per ton of sugar with Q. R. 10. Tare 8 per cent.

$\frac{\$396}{180\ TS}$ = $2.20 per ton of sugar with Q. R. 12. Tare 8 per cent.

If trash is increased 2 per cent,
Then $90 \div 102 = 88.2$ tons net cane per hour,
or $88.2 \times 24 = 2116.8$ tons net cane per day.

$\frac{2116.8}{10\ Q.R.}$ = 211.7 tons of sugar per day.

$\frac{\$396}{211.7\ TS}$ = $1.87 per ton of sugar Q. R. 10. Tare 10 per cent.

Notes on a New Species of Pyrophorus Introduced Into Hawaii to Combat *Anomala Orientalis* Waterhouse

By F. A. Bianchi

Pyrophorus bellamyi Van Zwal., the only known West Coast representative in Guatemala of a genus represented by two or more species in the eastern section of that republic, was introduced into the Hawaiian Islands by Dr. F. X. Williams and the writer during 1934 and 1935. Although neither adults nor larvae have yet been recovered in the field, it is hoped that in Hawaii the predacious larvae of this insect will eventually become an important factor in the control of white grubs, both Anomala and Adoretus, and if this happens the following notes, gathered incidentally in the course of work connected with the introduction, may prove of interest to Hawaiian entomology in general and to the sugar planters in particular.

Shipments and Technique:

Beginning with a first shipment in May 1934 and ending with one in April 1935, a total of 512 Pyrophorus larvae in various late stages of development was sent from Guatemala in five lots. Packed individually in tin pillboxes filled with sterilized soil slightly moistened, 466 out of the 512 larvae arrived in good shape. Most of them had keen kept and fed in the field laboratory for periods of from one day to three weeks and all were fed immediately before shipment, but no food was provided during the voyage. Upon arrival in Honolulu the original pillboxes continued to serve but the Guatemala soil was discarded in favor of soil from Oahu Sugar Company, Ltd., which thenceforth was changed twice a week. The majority of the Pyrophorus larvae was kept in the laboratory until emergence of the adults but 108 larvae were liberated as such, being shallowly buried on October 25, 1935 in the soil of fields 44 and 46 of Oahu Sugar Company. The adults were all liberated in various fields of this plantation, with the exception of one lot which was liberated in the Manoa Valley substation of the H.S.P.A. This lot consisted of nine males and 42 females and included several hundred very young larvae and eggs secured in the laboratory. The last liberation recorded took place on April 24, 1936 in field 55 of Oahu Sugar Company. It consisted of three males and four females reared from eggs laid in the laboratory in Honolulu.

Habits and Distribution of the Insect in the Field:

As R. H. Van Zwaluwenburg has recorded *(Proceedings of the Hawaiian Entomological Society,* 9:231-234, 1936), the adults of Pyrophorus are evidently of very secretive habits. To our knowledge only one has ever been seen in the field. This one was found by Dr. Williams early in the morning of June 16, 1934 on the foliage of a glandular compositae allied to Helianthus. In contrast to what might prove to be the case with *Pyrophorus radians* and other members of the genus, which in eastern Guatemala and elsewhere are easily found and often collected, the secretiveness of

bellamyi will probably be of advantage to it in the struggle to become established in Hawaii. In spite of its nocturnal habits it is not likely to become the prey of *Bufo marinus*.

So far *P. bellamyi* has been reported from within the confines of one plantation only—"El Salto"—a sugar cane plantation not far from the town of Escuintla, Guatemala. In this plantation the larvae, first observed by the writer early in 1933, were not evenly distributed, the great majority of those obtained for shipment to Honolulu having been found in one sporadically cultivated field some forty acres in extent near the plantation headquarters. This field was given to *Panicum maximum* during our stay in Guatemala and the soil was of soft texture and usually moderately moist; but several full-grown larvae were from time to time found in other fields where the soil was drier and harder. In the areas of abundance the larvae were found from one to sixteen inches below the surface of the ground; the majority in the neighborhood of six or eight inches. It is probable that at least in the later instars they depended for food mainly on the larvae of scarabs, the vertical range of dispersion of which roughly coincided with that of Pyrophorus.

It was obvious that the larvae covered considerable distances through the soil in search of food, and there was some indication that collective vertical migrations took place which may have been of seasonal occurrence.

In the few instances when pupae were dug up in the field they were invariably in the harder layer below the surface soil and rested, on their back in every case, within cells that seemed to have been made by repeated pushing of the pre-pupae against the soil immediately surrounding them. The cells were somewhat larger than their inmates permitting these to roll over without difficulty when disturbed.

No indication was found of any larval parasite of *bellamyi*, but in view of the enormous fertility of the female the relative scarcity of all stages of the insect in the field points to the existence of powerful inimical factors in its environment.

Adults kept in large jars in the laboratory were supplied with pieces of split sugar cane or with leaves smeared with honey. They seemed to take advantage of the food thus provided only very rarely, but one newly emerged female was seen actually feeding on the drops of honey. They were very sluggish under any conditions and spent most of the time resting on the pieces of cane or on the surface of the soil in the bottom of the jars, occasionally burying themselves just under the surface soil. On being picked up by hand they often, but not always, "played possum." We have never seen them in flight either in the laboratory or in the field; nor have they been observed mating or displaying the slightest interest in the opposite sex.

Brief Description of the Beetle:

Pyrophorus bellamyi was described as a new species by Van Zwaluwenburg. As the accompanying illustration shows (Fig. 1A), it is an insect generally resembling *Conoderus exul*, the well known click beetle of our cane fields, but it can be easily distinguished even by the layman from Conoderus by its much greater size and by its ability to emit a beautiful greenish phosphorescence which is easily visible even in daylight. While in the larva no exterior anatomical detail indicates this ability, in the adult two luminous organs are well defined as large, sub-oval, grayish

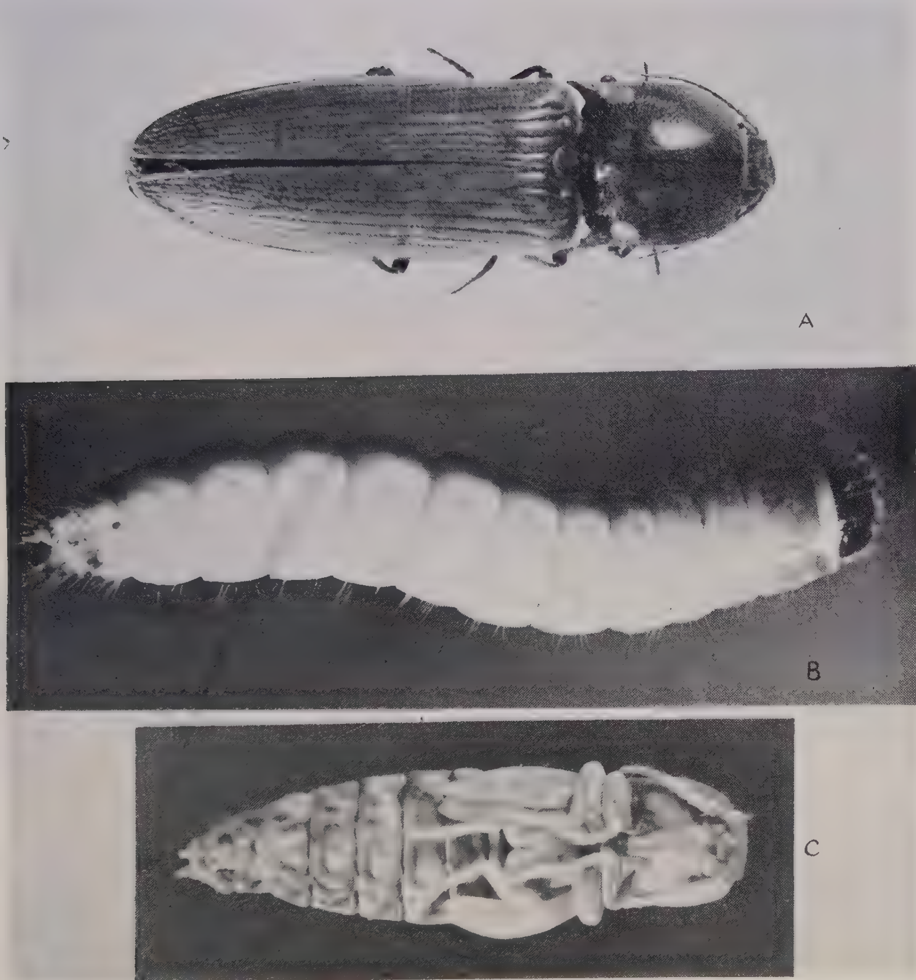

Fig. 1. *A*. Female beetle of Pyrophorus. Notice the gray areas near the hind angles of the prothorax; these are the luminous eye spots of the living insect. *B*. Full-grown larva of Pyrophorus. *C*. Pupa of Pyrophorus.

areas visible through the dorsal and the ventral cuticle covering of the posterior angles of the pronotum.

Differences between the sexes in the adult stage of Pyrophorus are perceptible only to the very careful observer, one of the most obvious being that in the female the prothorax is more convex and more robust in relation to the elytra than is the case with the male. In general, females can be distinguished by their greater length and girth, particularly when carrying a full complement of eggs; but, as the following measurements show, some overlapping occurs and size is not always a reliable criterion.

SIZE OF FEMALES

No. of item	Length from tip of mandibles to tip of abdomen in millimeters	Width of the base of the elytra in millimeters
1	35	9
2	33.5	9
3	32	9
4	31	8
5	31	8.5
6	31	8
7	31	8.5
8	31	8
9	30	7.5
10	30	8
11	29.5	7.5
12	29.5	7.5
13	29.5	7.5
14	28	7.5
15	28	7
16	25	6.5
17	25	6.5
18	21	5.5
	SIZE OF MALES	
1	24	6
2	24	6
3	23.5	6
4	20.5	5.5
5	20.5	5.5
6	19.5	5

Brief Description of the Larvae:

The larvae of Pyrophorus are active, elongate, cylindrically segmented insects not easily distinguishable by the layman from other wireworms of our fields. Pale white entirely, except for slight chitinization of the mouth parts and certain portions of the terminal abdominal segment, the first instar is very minute and inconspicuous and is hardly likely to be seen outside of the laboratory. Five mounted specimens measured micrometrically 2.5, 2.6, 2.7, 2.25, and 2.55 millimeters in length respectively. The second instar may or may not have perceptibly increased in size; it shows but slight enlargement and intensification of the chitinous areas and can best be distinguished from the first instar by the changes which appear in the ninth abdominal segment, which our illustrations show (Fig. 2A and B). In the third, or possibly in the fourth instar an uncertain point—the larva becomes more heavily chitinized in the head and distal regions, and in all but its smaller size and paler coloring assumes the appearance of the full-grown wireworm.

The fully developed larva is illustrated in Fig. 1B. The insect in this stage is comparable in size only to the larva of *Chalcolepedius erythroloma* among the Elaterids found in Hawaii. The head and mouth parts; certain tubercules of the ninth and tenth abdominal segments; parts of the legs; and the dorsal sclerite of the first body segment are heavily chitinized. The cuticle is everywhere tough, almost leathery, yellowish in color, and the whole insect is a vigorous, very hardy individ-

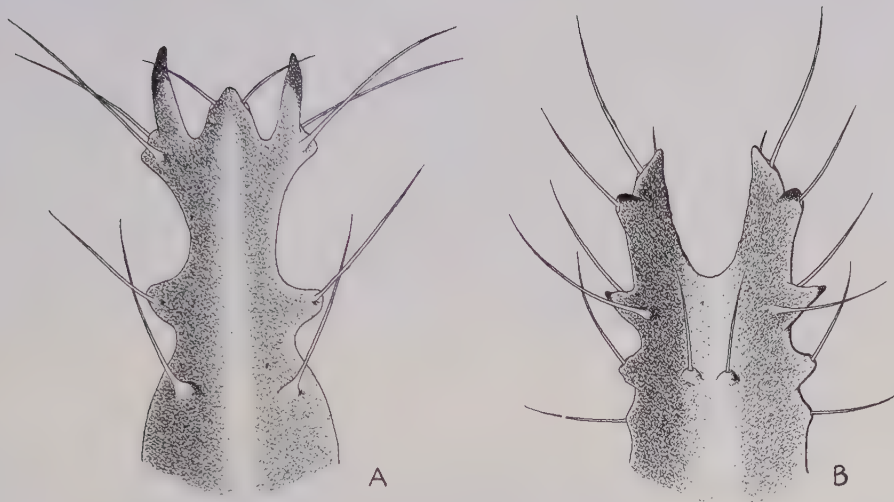

Fig. 2. *A* and *B*. Dorsal appearance of the ninth abdominal segment in first and second instars of *Pyrophorus bellamyi*.

ual capable of withstanding much rough handling, prolonged periods of starvation, and a wide range of temperature and moisture conditions. One larva showed no ill effects when relieved of a thick accumulation of mites with a brush dipped in carbolic acid.

Rough measurements of the body length of seven individuals measured during the last larval instar were 32, 34, 35, 37, 38, 42, and 50 millimeters respectively. The weight of one of the largest larvae we have observed was 1,450 milligrams.

In contrast to other measurements, the greatest width of the ventral mouth parts showed only occasional variation from the norm among the last larval instars of individuals collected in the field. A series of 13 random measurements made on the last moulted larval skins gave the following results in millimeters: one of 1.980, one of 2.442, seven of 2.640, one of 2.706, two of 2.772, and one of 2.970.

The first case in the list (one of 1.980) proved to be the larva of an undersized male which may not have moulted as many times as the others.

The pupa of Pyrophorus, as can be seen in the accompanying illustration (Fig. 1C), is also very much like the corresponding stage of our other Elaterids. It is more than twice the size, however, of any similar pupa likely to be found in the cane fields.

The Luminescence of Pyrophorus bellamyi:

Because of its greenish quality the luminescense produced by the larvae and adults of Pyrophorus is visible even under fairly strong natural or artificial light. In the adults it is present at all times but the larvae may go long periods without showing it. Whether the ability to produce it ever completely and permanently disappears is not known but it was distinctly observed that field-collected larvae were less apt to glow in the laboratory after a few moults than they had been in the field. It is not recalled, in fact, that any larvae failed to glow when first handled in

the field or that any failed to react in a similar manner for several days later, whenever they were disturbed.

When luminescence is present either in larvae, pupae, or adults it is constant at a certain minimum of intensity. At this minimum it may be hardly perceptible or easily distinguishable but both the intensity of the light and the extent of the luminescent areas increase suddenly when the insect is prodded or shaken. A maximum of intensity is then quickly reached, followed by a more gradual return to the constant minimum. This wave-like increase and decrease of intensity occurs in the pupae, pre-pupae, and adults of Pyrophorus as well as in the larvae and is not confined to any particular luminous area of the body, extending simultaneously, or nearly so, to all of them. It is seemingly a voluntary reaction with a protective purpose and in the case of luminescent larvae it is invariably associated with the act of biting, when the individual is sufficiently aroused to have recourse to this more vigorous defense.

In active larvae the luminescent area includes as a rule only the first segment of the body, the prothorax, which may be luminescent ventrally and dorsally over its whole width or, very often, only over a more or less narrow anterior portion. In striking contrast, during the inactive pre-pupal and pupal stages, and very rarely in the case of active larvae, as well, the light-producing organs seem to become released from their usual anchorage and, being distributed somehow throughout the body, cause luminescent areas to appear on other segments. In some specimens the entire body, including the head, glows beautifully and, as the light appears more brightly in these cases along the transversal sutures of the body, the insect is strikingly outlined in greenish light.

In fully developed adults luminescence is limited to some of the dorsal sutures of the body and to the ventral and dorsal surfaces of the posterior angles of the prothorax, where it appears in the large sub-oval areas mentioned earlier. It has been noted, however, that recently emerged adults, in which chitinization has not taken place, are luminescent throughout the entire body in a manner similar to that of the pupae and pre-pupae.

Luminescence has not been observed by us in either the eggs or the very young larvae of *Pyrophorus bellamyi*, the youngest individual in which luminescence was apparent having already reached the third or fourth instar of its growth. Luminescence was limited in this case to the first segment of the body and its intensity increased in response to stimuli in the wave-like manner discussed above but the waves were of distinctly shorter duration than in the case of larger larvae.

In two out of four larvae in which luminescence had not been apparent for many weeks it appeared suddenly and fairly strong when the larvae were plunged into cold water. As no luminescence had previously been obtained from any of these four larvae, even by vigorous shaking and prodding, this observation perhaps explains why women and children in Mexico used to "bathe" the "cucuyos," a species of Pyrophorus closely related to *bellamyi*, which during Colonial days were worn as adornments in little gauze bags pinned to the hair. (Insect lore of the Aztecs, C. H. Curran, *Natural History*, 39: 196-203, 1937). Our observation, however, was made on the larvae of Pyrophorus and we have had no opportunity to ascertain whether it also applies to the adults.

Cases of Prothetely:

Prothetely is the term applied to the abnormal condition of larvae showing precocious development of pupal or imaginal characters.

As has been observed to be the case with other insects, the incidence of this condition among larvae of *Pyrophorus bellamyi* seems to increase greatly under laboratory conditions. Out of nearly 600 larvae collected in El Salto not a single prothetelous example was found, but at least four larvae developed prothetely after being kept in the laboratory for a time. Three of these died before reaching the pupal stage, but one underwent two larval moults and pupated, eventually emerging as a perfectly normal female. The laboratory record of this individual is as follows:

March 29, 1933: A larva about half-grown found under cane trash in El Salto. Fed one or two grubs per diem until May 18. Was not fed at all between May 18 and June 23. Resumed usual rate of feeding on June 23, and between this date and the date of pupation consumed 53 large or medium sized grubs and two Scarab pupae.

July 10, 1933: Shed normal skin and new instar appeared with two wing pads on each side of the thorax. The pads appear to be pointed, egg-shaped evaginations of the body wall filled either with body juices or air. They can be pinched or pressed out of shape to some extent but quickly regain their former outline when the pressure is removed. They are considerably constricted at the point of attachment to the body. The posterior one folds closely against the body and the anterior one folds closely over the posterior one. They are not very different in size and measure about 3.5 millimeters in length by 2 millimeters at the point of greatest width.

November 22, 1933: Shed again without difficulty and wing pads appeared considerably reduced in size and altered in shape. They are now lightly chitinized tubercules somewhat constricted at the base.

December 28, 1933: Moulted again. Mesothoracic pads disappeared completely but prothoracic pads remained unaltered in shape and only slightly reduced in size.

April 9, 1934: Transformed into a perfect pupa after a short and not clearly defined pre-pupal rest period.

April 17, 1934: Normal, fair-sized adult female emerged.

June 20, 1934: Adult died.

Unfortunately the series of photographs presented herewith (Figs. 3 A, B, and C) is not of the larva which successfully reached the adult stage but of one of the other three which died in the attempt. The photographs give a very good idea, nevertheless, of the general appearance of the wing pads in all our four cases of prothetely and of the changes they underwent in successive moults in the three cases where the larvae died.

Measurements of the mouth parts of two of the larvae which died before pupating showed they had probably reached full larval growth at the time of their death. The mouth parts of the last two successive moults, in the case of one of these larvae, both measured 2.60 millimeters in width, showing that no body growth had taken place during the last two prothetelous instars. The death of all three larvae occurred during the process of moulting or shortly after an incomplete moult.

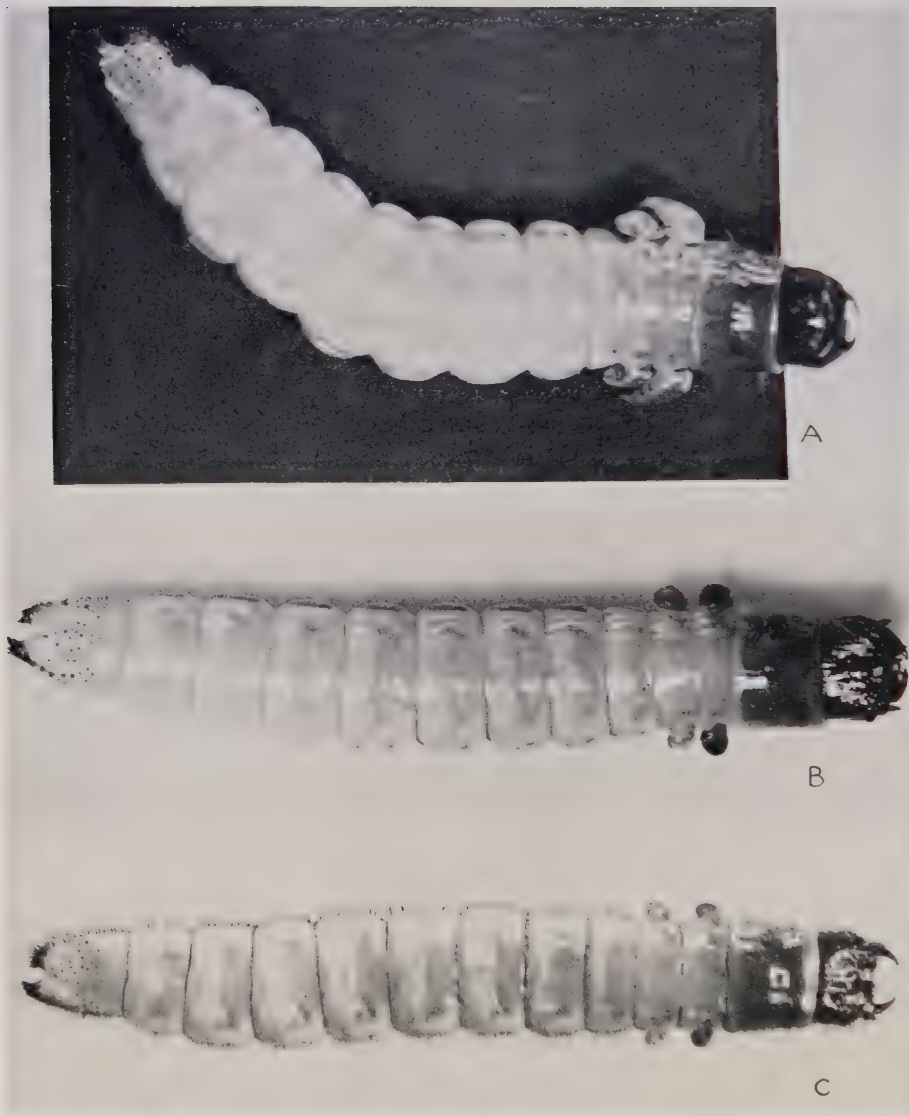

Fig. 3. *A*, *B*, and *C*. Showing the gradual reduction of the wing pads in three successive instars of a prothetelous larva of *Pyrophorus bellamyi*. This larva died in the condition shown in *C*.

Life History

Oviposition:

Females kept in large jars partly filled with loose soil did not group their eggs in any particular manner but distributed them unevenly throughout the soil.

Records of oviposition were obtained in Honolulu from two females emerged from larvae collected in the field at El Salto. Both of these were placed with a male within a day of their emergence. The first produced two batches of eggs; one batch of approximately 300 eggs was laid 35 days after the emergence of the mother; the

second batch, 385 eggs, was laid 20 days later, or 55 days after the emergence of the mother and only two days before her death. No count was made of any eggs which may have remained within this female after death. The second female also laid her eggs in two batches, both of 91 eggs; the first batch laid 43 days and the second batch 64 days after emergence of the mother and shortly before her death. This female still retained 1,292 fully formed eggs within her body after death, so that her total potential production amounted to 1,474 eggs. A third female, dissected before oviposition had taken place, yielded a total of 4,425 eggs.

As oviposition was not timed in any case, the period of incubation was not ascertained, but it appears to be shorter than the 10 to 16 days which Wolcott gives for the related *Pyrophorus luminosus* Illiger. (El Cucubano, Circular No. 80, Departmento de Agricultura y Trabajo, Gobierno de Puerto Rico, 1923.)

The Eggs:

The eggs of *Pyrophorus bellamyi* are spherical, milk-white, slightly shiny, and so smooth that they show no sculpturing even under high magnification. Micrometrical measurements of 11 eggs dissected from a gravid female preserved in alcohol showed two with a diameter of .50 millimeter, two with .48 millimeter, four with .46 millimeter, and three with .44 millimeter, giving an average diameter of .465 millimeter for the lot.

In the laboratory, close observation has not revealed to the writer at any time the luminescence in the eggs of *P. bellamyi* which is said to be apparent in the eggs of related species. Possibly it occurs under hitherto undetermined conditions.

Number of Instars:

As is known to be the case with most insects, the gross size of Pyrophorus larvae does not provide an accurate criterion of their age or the number of moults which they may have undergone. A satisfactory criterion is provided by the size of the head capsule, which according to Dyar's Law (The Number of Molts of Lepidopterous larvae, H. G. Dyar, *Psyche,* 5: 420-422, 1890) follows regular geometric progression in successive instars. This does not mean, of course, that the head capsules of all the individuals of a certain instar will be of exactly the same size but that their measurements will fall between two well-defined limits of a mathematical interval. Our data are insufficient to permit definition of these intervals in the case of Pyrophorus but provide an approximate indication of what they may be for certain instars, as is shown in Table I.

TABLE I

Showing the greatest width in millimeters of ventral mouth parts shed by Pyrophorus larvae during successive moults preceding pupation. "P" indicates the point at which pupation occurred. It is not known in the case of any of the larvae here tabulated how many moults may have preceded those whose measurements are given.

Lab. No. of Specimen	Greatest Width in Millimeters								
A1	..	.86	1.02	1.28	1.60	P			
A2	.66	.80	1.00	1.30	1.56	P			
A3	.62	.80	1.10	1.50	1.64	P			
A4	.70	.90	1.10	1.40	1.60	P			
A5	..	.84	1.18	1.46	1.60	1.75	2.00	2.05	P
A6	..	.84	1.08	1.44	1.60	P			
A7	..	..	1.02	1.28	1.46	P			
A8	..	.68	.88	1.20	1.60	1.85	P		

This table, following McDougall's rather than Dyar's example, gives the greatest width of the ventral mouth parts, rather than the greatest width of the whole head capsule. For various reasons (The Determination of Larval Instars and Stadia of Some Wireworms—Elateridae, W. A. McDougall, *Queensland Agricultural Journal* 42: 43-47, 1934) this is an easier measure to obtain and probably a more accurate one. The mouth parts were measured on each exuvia after ecdysis and measurements were made by means of a simple micrometer eyepiece and objectives of powers suited to the various sizes found.

No complete series of measurements was obtained for any one individual and it has not been ascertained beyond question how many times the larvae of *P. bellamyi* moult as a rule before pupation. Our data indicate that probably seven larval ecdysis are undergone in the majority of cases but that sometimes more and sometimes less than this number of moults occur. In Table I the two series of items, A5 and A8, which extend to the right beyond the rest of the items were so placed arbitrarily and are presumed to represent two larvae which lived longer and underwent, respectively, one and two moults more than the others show in the table. This presumption is justified by the fact that the items of series A5 and A8 agree more closely with the other items of the table when so arranged.

Measurements of the ventral mouth parts of a series of sixteen first instars showed widths of .165 millimeter in seven cases and of .132 millimeter in nine cases. The measurements of 16 second instars were all .264 millimeter.

Deviations from Dyar's Law:

Although Dyar's Law evidently applies to Pyrophorus generally enough to retain its validity and usefulness, deviations from the law have been noticed. In the case of three larvae which have been under observation in the laboratory for a long time but whose record is not given in Table I, it has been found that the last two, and in one case the last three, successive mouth-part measurements have not perceptibly varied. Cessation of growth is undoubtedly indicated, but it has not been determined whether growth has ceased permanently or temporarily for the larvae in question are still alive and may moult again before pupation.

Duration of Larval Life:

Lacking field data altogether we judge from laboratory records that the total length of larval life of Pyrophorus is subject to great variation. Table II indicates a very wide range for the duration of every stadium and in regard to the total duration of larval life shows about an equal division between larval lives of approximately one year and those which extend to nearly two years; but one larva not included in the table, hatched from an egg laid in the laboratory on June 1, 1934, has moulted at least six times, and still seems as far as ever from pupation after three years of observation.

That in nature two rather than one year may be the general duration of larval life is indicated by the fact that the majority of the larvae collected in El Salto did not pupate until approximately one year later, although all of them were already large-sized larvae when collected, and although all of them were probably fed more regularly and abundantly after being captured than they could have fed themselves

TABLE II

The dates in the columns numbered from I to VI refer to successive larval moults; the numbers between the dates give the duration in days of the corresponding stadia.

Lab. No. of Specimen	VI		V		IV		III		II		I		Date of Pupation	Duration in days of the pupal period	Date of emergence of adult
B1	5/20/35	23	6/13/35	63	8/15/35	63	10/17/35	24	12/10/35	51	1/30/36	73	4/11/36	..	......
B2	......	..	5/20/35	60	7/19/35	84	10/10/35	47	11/26/35	24	12/20/35	108	4/ 6/36	15	4/21/36
B3	......	..	......	..	......	..	5/ 2/35	22	5/24/35	92	8/24/35	228	4/ 8/36	16	4/24/36
B4	......	..	......	..	......	..	5/ 6/35	135	9/28/35	179	3/25/36	17	4/11/36	..	......
B5	......	..	5/ 7/35	27	6/ 3/35	70	8/22/35	56	10/17/35	101	1/30/36	64	4/ 2/36	..	......
B6	......	..	6/17/35	79	8/24/35	33	9/16/35	21	10/ 7/35	27	12/ 3/35	127	5/ 8/36	18	5/26/36
B7	6/20/35	38	7/20/35	31	8/20/35	37	9/26/35	62	11/26/35	50	1/14/36	62	3/16/36	16	4/ 1/36
B8	......	..	......	..	7/15/35	40	8/24/35	37	9/30/35	51	11/19/35	139	4/ 6/36	13	4/19/36
B9	6/17/35	64	8/20/35	20	9/ 9/35	22	9/30/35	25	10/24/35	48	12/11/35	100	4/20/36	17	4/ 6/36
B10	......	..	9/ 4/35	15	9/19/35	18	10/ 7/35	55	12/11/35	45	1/25/36	161	7/ 4/36	17	7/21/36
B11	......	..	8/10/35	20	8/30/35	27	9/26/35	76	12/11/35	35	1/25/36	51	3/16/36	16	4/ 1/36
B12	......	..	8/10/35	30	9/ 9/35	22	10/ 1/35	64	12/ 3/35	64	2/ 5/36	61	4/ 6/36	13	4/19/36

in the fields. The fact that many field-collected specimens continued to grow in the insectary, some moulting as many as five or six times therein, precludes the supposition that the long life of the larvae in the laboratory might be due to unusual protraction of the last stadium in consequence of unnatural conditions.

Because the duration of the third stadium has not been recorded, and that of the first and second stadia only in a few cases which do not correspond to those recorded in Table II, these stadia are not shown in the table. The first stadium in four cases lasted approximately 17, 17, 22, and 22 days, respectively. The second stadium in two cases lasted 13 and 63 days respectively.

The Pre-Pupal Stage:

Both the duration of the pre-pupal period and the condition of the larva during that stage are apt to vary widely with *Pyrophorus bellamyi*. When the period is short, around six days but sometimes less, it is marked simply by pronounced sluggishness and is not accompanied by any change in the external appearance or behavior of the larva. When the period is long, extending to an observed maximum of 21 days, the larva lies almost invariably on its back; and the legs, completely immobile, are held closely folded against the body. Inactivity is then complete in many cases; but in others the larva, although unable to move its legs, will wriggle vigorously when prodded and will sometimes turn over and over with a curious and characteristic spiral motion which is often accompanied by convulsive movements of the mouth parts and sometimes by the sudden appearance or sudden intensification of light in the luminescent portions of the body.

Duration of the Pupal Stage:

Duration of the pupal stage as recorded under laboratory conditions varies between a maximum of 20 days and a minimum of 12, with a series of 215 observations distributed as follows:

2 cases of 12 days	33 cases of 15 days	24 cases of 18 days
25 " " 13 "	27 " " 16 "	5 " " 19 "
51 " " 14 "	46 " " 17 "	2 " " 20 "

Nearly three-fourths of the items fall in the 14-17 days interval and the average of the series is 16.3 days.

Duration of the Adult Stage:

As will be seen from the following tabulation, our data are insufficient to render a reliable average for the duration of the adult life of *Pyrophorus bellamyi*. Both males and females are evidently apt to range very widely in this respect.

All the figures are from adults emerged in the laboratory from field-collected larvae and kept over soil in jars, without feeding.

Sex	Date of Emergence	Date of Death	No. of Days Lived
Male	3/19/34	5/20/34	63
Male	6/30/35	7/18/35	19
Unrecorded	4/17/34	6/20/34	64
Female	1/10/34	1/30/34	20
Female	4/30/34	5/20/34	21
Female	4/20/34	5/12/34	22
Female	3/22/34	4/18/34	27
Female	4/20/34	5/27/34	37
Female	5/8–11/34	6/23/34	43–46
Female	4/28/34	6/16/34	49
Female	4/18/34	6/21/34	64
Female	3/19/34	6/ 1/34	84

Food Habits of the Larvae:

Pyrophorus larvae are exclusively carnivorous. Confined in jars in the laboratory they are also pronouncedly cannibalistic, particularly the early instars. They can probably be fed on a wide variety of other insects but we fed them during the later stadia exclusively on a diet of scarab larvae and pupae of various species and during the early stadia on a diet of termites and Psocids. The latter were put into the Pyrophorus jars with the leaves and humus in which they were found.

In attacking scarab grubs the Pyrophorus seem not always to be motivated by hunger but by some sort of natural antipathy. On meeting with a grub in the bottom of an empty jar they almost invariably endeavor to bite it, but as far as has been observed they never continue to feed on the grub until both grub and Pyrophorus are covered with soil. The first bite of their attack seems to be impulsive and in the spirit of self defense, often hastily pinching the enemy in some soft portion of the body and quickly releasing it again. When thoroughly aroused, nevertheless, the Pyrophorus larva will often work the scarab grub between its jaws until these can be securely clamped on the head capsule of the grub. The hold is then seldom released until the capsule is crushed and the grub is put completely out of commission. As the larvae feed only in the soil they have not been actually observed in the act but the evidence of grub remains indicates that Pyrophorus feeds on the body tissues of the victim while gradually pushing itself into the body through a ragged hole chewed out in some anterior portion of the body wall. The head capsules and the thoracic and middle segments of the bodies of white grubs are usually found emptied but the hindmost ventral segments within which are found the dark contents of the gut are always left intact.

In Table III are given the laboratory feeding records of six field-collected larvae which were reared to full maturity under observation. Influenced greatly by the unavoidably meager and inconstant rate at which the larvae were fed, the data of this table give only an approximate idea of what the quantity of food may be which is essential to the complete development of Pyrophorus. The maximum number of white grubs which each Pyrophorus larva might destroy in the field is entirely a matter of guesswork and is probably a number more dependent on the density of scarab population, the consistency of the soil, and other factors than on the gastronomic capacity of Pyrophorus.

TABLE III

Showing the number of white grubs consumed by each of six field-collected Pyrophorus larvae kept until pupation in jelly jars partly filled with soil. As all the Pyrophorus were already approximately half grown when collected these records cover only the last half of any individual's life.

Lab. No. of Pyrophorus	Date of first feeding	Date of last feeding	Total number of days in laboratory	Number of grubs consumed	Avg. No. of days per grub
C1	4/ 8/33	4/ 9/34	365	69	5.3
C2	6/19/33	2/17/34	242	31	7.8
C3	4/24/33	3/14/34	323	61	5.3
C4	5/ 7/33	4/20/34	347	54	6.4
C5	3/29/33	3/10/34	345	55	6.2
C6	1/19/33	1/ 3/35	712	126	5.6
				Grand Average	6.1

In the laboratory, and probably also in the field under favorable conditions of grub abundance and accessibility, a great many more grubs are killed through being simply injured than are either partly or wholly consumed as food. Thus, when confined in a small jelly jar, four grubs a day were destroyed by one Pyrophorus larva every day for a period of two weeks.

As a rule a period of fasting is undergone by the larva of Pyrophorus just before each ecdysis. It may last from three to four days or may be prolonged to 10 or 12 and is often accompanied by perceptible diminution of the larva's activity. It is usually longest as a prelude to the inactive pre-pupal stage which precedes the last larval moult.

Pyrophorus vs. Scolia manilae:

It has been suggested that Pyrophorus might interfere with the usefulness of *Scolia manilae*, but we do not believe it can do so to any significant extent.

This belief is based principally on the following facts:

First: Due to the shortness of Scolia's larval stage in comparison to the total larval life of its host the chances that the host will be attacked by Pyrophorus during the critical period—that is, while the white grub is bearing the egg or the larva of Scolia—are relatively few.

Second: These chances are reduced through the fact that a considerable proportion of the white grubs parasitized by Scolia are found in deeper, harder soil than Pyrophorus is likely to frequent in the presence of the loose upper layer which almost universally covers a cultivated field and which as a rule harbors the majority of Anomala grub populations.

Third: The chances are further reduced through the invariably complete paralyzation of white grubs during the period when they are used as hosts by Scolia, and by the fact that during this period a large proportion of grubs lie in cavities whose walls are packed to a hardness considerably greater than that of the surrounding soil.

It has been determined that the larvae of Pyrophorus will attack and destroy both the active grubs of Anomala and those which have been paralyzed by the sting

of Scolia, but in the laboratory it has been found that in the presence of both paralyzed and active grubs the former are much less likely to be attacked than the latter.

It is not unreasonable to suppose that this same tendency will be found in the field, possibly more pronounced.

To determine the preference of Pyrophorus larvae for active or paralyzed grubs four large larvae were used. They were kept separately in small jelly tumblers partly filled with soil and each was provided daily with two third instar grubs of Anomala, one intact and one paralyzed by Scolia within the 12 preceding hours. The two grubs were in every case placed simultaneously in the bottom of the tumblers and the soil and Pyrophorus, previously removed, were put in afterwards. No grub, either intact or paralyzed, was used twice in the experiment and the slightest evidence of injury was taken as sufficient to place the particular grub in the "attacked" class. Observation and change of grubs were carried out at approximately the same hour for seven consecutive days and the results obtained were as follows:

Total number of white grubs used in the experiment...........	28 active and 28 paralyzed
Number of paralyzed grubs attacked by Pyrophorus...........	16
Number of active grubs attacked by Pyrophorus..............	25
Number of paralyzed grubs not attacked by Pyrophorus........	12
Number of active grubs not attacked by Pyrophorus...........	3

It is to be expected that Pyrophorus, once established in our cane fields and present in sufficient numbers, rather than interfering with the work of *Scolia manilae,* will supplement the work of the wasp in just such a manner as to reduce greatly the importance of the Anomala problem. The ability of the larvae of Pyrophorus to live and feed under the thick matting of cane which covers every field during the latter part of each ratoon, and which tends to impede the entrance of Scolia, may eliminate what is probably the principal cause of Anomala's lately heightened level of abundance.

Absorption of Mineral Nutrients by Sugar Cane at Successive Stages of Growth

By Arthur Ayres

The chemist is frequently called upon to assist in the solution of problems involving the subnormal growth of sugar cane. Such growth may have resulted either from pathological causes or from inadequate, or unbalanced, nutrient supply. The chemist assists in such work by determining the mineral composition of the specimens under consideration. By the same means, he has also been of assistance to the agriculturist in his studies of soil fertility. Studies such as these properly require comparison with normal or control canes in which all growth factors, other than the one under consideration, are identical. Often, however, such comparisons are impracticable, if not impossible. In such cases it has usually been necessary either to ignore, or to make generous allowances for, the effects of these growth factors upon the composition of the plant. For these reasons, a program of study was begun which would yield, in a degree, the understanding necessary to the interpretation of data resulting from such investigations.

Aside from the nutrient supplying power of the soil, the age of the cane plant is probably the greatest single factor influencing its mineral composition. In accordance with the program outlined above, the writer (1931-33) analyzed representative samples of sugar cane at periodic intervals from a plot set aside for the purpose at the Experiment Station. The results of this work showing the effect of age upon the composition of the cane plant were subsequently reported in *The Hawaiian Planters' Record* (2).

At the conclusion of the experiment, the remaining cane was harvested and a similar study of the succeeding ratoon crop begun. In the case of the ratoon crop, however, it was decided to investigate not only the effect of age upon the composition of the cane plant, but also the actual rates at which the principal mineral nutrients are taken into the plant. This was to be accomplished through periodic determination of the total quantities of nutrients contained in the stalk, green leaves and accumulated dead leaves of the cane plant. The purpose of this phase of the investigation was to obtain information which would reveal in greater detail than the earlier studies by Stewart (6) and by Stewart and the writer (1) the changing demands which the growing cane plant makes upon the soil for mineral nutrients. Knowledge of these demands at successive stages of growth would, it was felt, enable the agriculturist more nearly to adapt his program of fertilization to meet the needs of the crop. The present paper deals with the investigation of these matters in relation to the ratoon crop.

Experimental

The experimental plot consisted of approximately 1,000 running feet of cane in rows five feet apart. The variety of cane grown in the experiment was H 109, first ratoon. In order to avoid as far as possible any effect upon the rate of absorption of even temporarily localized concentrations of mineral nutrients, a soil (Field 8,

Makiki) was selected for the study which would require no fertilizer other than nitrogen to produce a normal crop of cane. The amounts of the principal nutrients present in the soil of the experimental plot, as measured by extraction with one per cent citric acid, are shown in Table I. The data, which are expressed in terms of pounds of nutrients per acre-foot of soil, indicate supplies of these materials which are generally considered adequate for the production of a crop of sugar cane.

TABLE I

POUNDS OF AVAILABLE NUTRIENTS IN SURFACE ACRE-FOOT OF SOIL*

Silicon (Si)	Calcium (Ca)	Potassium (K)	Phosphorus (P)
4,600	13,000	775	2,750

*It will be noted that the quantities of nutrients shown in the table are expressed in terms of the elements and not as the oxides of the elements, as is frequently done. There is a growing tendency among publishers and readers of scientific literature to insist upon the employment of the more fundamental unit of the element itself rather than of the oxide, or other compound of the element. This is manifestly the more logical procedure where, as in the present case, no attempt was made in the course of the analyses to determine the exact nature of the compounds in which the elements were present, but simply the quantities of the elements themselves. In so expressing the data, we have only reduced these nutrients to the same basis as that which has long been accepted in the case of nitrogen, which is always given in terms of the element rather than as one of its numerous oxides. That a truer picture of the relative quantities of nutrients taken up by the cane crop is obtained when we consider the elements themselves, in place of their oxides, will be seen by the following illustration. In Experiment E, Waipio (1), it was found that at the age of 12 months the stalks, green leaves and dead leaves in an acre of cane together contained 390 pounds of potash (K_2O) and 710 pounds of silica (SiO_2), or more than 4/5 again as much SiO_2 as K_2O. When, however, we express these quantities in terms of the elements we find that the amount of potassium (K) absorbed was 324 pounds and of silicon (Si) 332 pounds, or nearly equal amounts, which is quite a different picture. Conversion of data from one form to the other may readily be accomplished by means of the following factors: Ca=0.715 CaO; K=0.830 K_2O; P=0.437 P_2O_5; Si=0.467 SiO_2; Mg=.603 MgO.

Nitrogen in the form of ammonium sulfate was applied in amount corresponding to that which is generally used under similar field conditions by the plantations. A total of 200 pounds of nitrogen was applied as follows: August 24, 1933, 50 pounds; September 1, 1933, 50 pounds; December 26, 1933, 50 pounds; and September 24, 1934, 50 pounds.

The experimental area was planted in August 1931, and ratooned two years later in August 1933, when the present investigation was begun. The plot was sampled at monthly intervals, beginning one month after the start of the ratoon crop and continuing until the age of 14 months. Samples were selected in accordance with a carefully developed plan which was deemed well suited to the shape of the plot, the number of stalks to be removed per month and the total number to be harvested in the course of the study. Not more than a single stalk was cut from a stool of cane. Outside rows which were necessarily subjected to more light and wind than inner rows did not contribute to the samples. Thirty stalks were selected at each harvest during the first four months and subsequently 20 stalks. Specimens were selected from the normal, vigorous members of the original stand of cane.

Dry leaves appeared during the fourth month. Beginning with the fourth harvest, therefore, stalks to be cut at each succeeding period were tagged and stripped of adhering dry leaves. Hence, dry leaves present on the stalk at sampling one month later, plus those removed for safekeeping during the interim, represented the formation of this material during the preceding month. The crop passed through the first winter without tasseling. Extensive tasseling occurred the second winter and was already in evidence at the last period of harvest in October 1934.

Immediately upon cutting, the plants* were removed to the laboratory where the dead leaves, green leaves and stalks were separated. The plant material was then freed from extraneous matter by careful cleaning with dampened cloths. In order that the distribution of nutrients in the stalk might be studied, that part of the plant was divided into sections as indicated below:

From tip of growing point, 6 inches down stalk........Section A
From base of Section A, 3 feet down stalk........Section B
From base of Section B, 3 feet down stalk........Section C
From base of Section C, 3 feet down stalk........Section D
From base of Section D, 3 feet down stalk........Section E

This division was in part arbitrary and in part influenced by the results of earlier investigations.

Since the plants were severed at the surface of the ground, there was usually a section of each stalk which did not find a place in the above classification. These pieces comprised an additional sample which, like the other samples, was weighed and subsequently analyzed. Determinations of the composition of the roots were not made. Dry weights of all plant materials harvested were obtained. Because the immediate stages in the preparation of the plant materials for analysis were time-consuming, samples were taken early in the day. Frequently at these times the cane was thoroughly wet as a result of early morning showers. This situation was further aggravated as a result of transpiration losses by the leaves during the period required to obtain the samples and, in many instances, rendered futile attempts to secure accurate green weights. Sampling was discontinued at the age of 14 months. This was made necessary by the lodged and tangled condition of the cane at this age and the consequent impracticability of obtaining further representative samples.

Analytical Procedure

Determinations were made in duplicate upon the partially dried (1 to 5 per cent moisture) comminuted material by the methods given below:

Moisture: By drying to constant weight under vacuum at 80° C.

Ash: By overnight ignition in an electric muffle at 400° C.

Silicon: By the hydrofluoric acid method; occluded material remaining after destruction of the silicon being added to the filtrate from the silicon.

Calcium: By removal of silicon, iron, aluminum, and phosphorus from the hydrochloric acid extract of the ash and volumetric determination of calcium as the oxalate.

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* For lack of a proper name the word "plant" is frequently used in this paper to designate the aerial portion of the cane stalk plus the accompanying leaves.

Magnesium: By the removal of silicon, iron, aluminum, phosphorus, and calcium from the acid extract of the ash and determination of magnesium by double precipitation of magnesium ammonium phosphate and subsequent ignition to magnesium pyrophosphate.

Potassium: By the removal of silicon, iron, aluminum, phosphorus, and calcium from the hydrochloric acid extract of the ash and the determination of potassium by the Lindo-Gladding method (as potassium chloroplatinate).

Phosphorus: By separation with iron from the hydrochloric acid extract of the ash (following removal of silicon) and subsequent determination by the volumetric ammonium molybdate method.

Nitrogen: By the Gunning method for total nitrogen.

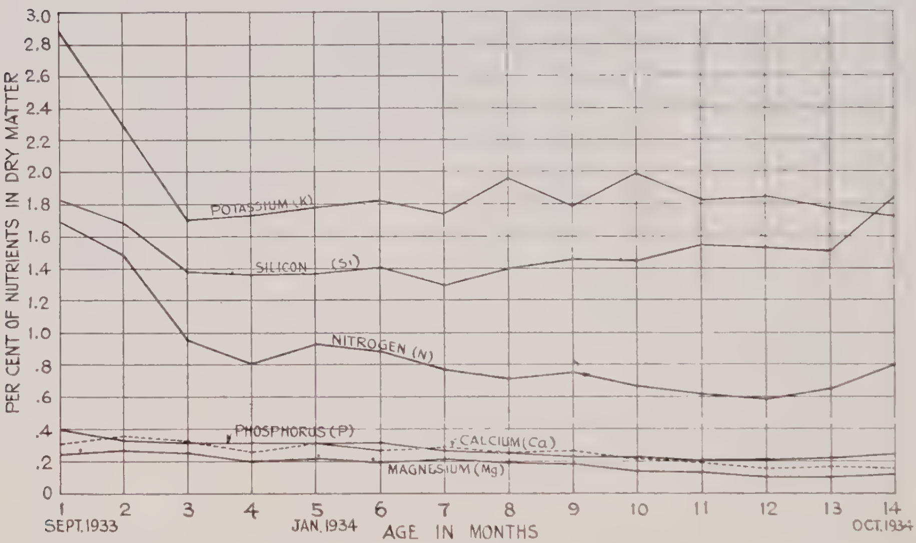

Fig. 1. This chart shows the changes which took place with age, in the mineral composition of the green leaves.

Discussion

Effect of Age Upon the Percentage Composition of the Green Leaves:

In Table II and in Fig. 1 is shown the percentage composition of the dry matter of the green leaves, at intervals of a single month, from one to 14 months. Referring to the figure, it will be observed that marked decreases in the concentrations of potassium, silicon, nitrogen, and phosphorus occurred during the first three to four months of growth. Between this period and the age of one year, changes were generally less pronounced. During the final two months of the experiment, the percentages of several of the nutrients in the leaves increased. These final changes appear to have been associated with the preparation of the plant to tassel. The increase in nitrogen during this period was doubtless, in part at least, the result of an application of ammonium sulfate to the experimental plot at the age of 13 months. It is of interest to note that whereas the percentages of the three principal mineral

constituents of the leaves and of phosphorus decreased during the initial months of growth, those of calcium and magnesium increased slightly during the same period. The same dissimilarity was observed in the plant crop and indicates an early rapid movement of these two bases into the leaves. With the exception of silicon, the changes with age in the composition of the leaves of the ratoon crop were similar to those observed in the plant crop.

TABLE II

PERCENTAGE COMPOSITION OF DRY MATTER

Age	Ash	Si	Ca	K	Mg	P	N
			STALKS				
Age	Ash	Si	Ca	K	Mg	P	N
2 months	13.67	.23	.46	3.39	1.13	.85	2.36
3 months	8.42	.38	.29	2.19	.60	.49	.93
4 months	6.06	.42	.16	1.59	.33	.37	.48
5 months	4.45	.33	.093	1.19	.21	.26	.44
6 months	3.57	.28	.064	1.00	.15	.22	.36
7 months	2.65	.23	.058	.70	.13	.17	.22
8 months	2.33	.20	.044	.59	.10	.15	.18
9 months	2.10	.18	.041	.55	.097	.14	.15
10 months	2.03	.16	.037	.50	.078	.14	.13
11 months	2.03	.21	.049	.46	.097	.16	.10
12 months	1.80	.16	.039	.46	.078	.14	.092
13 months	1.65	.16	.036	.40	.072	.14	.098
14 months	1.73	.17	.038	.42	.072	.14	.12
			GREEN LEAVES				
1 month	11.40	1.84	.31	2.89	.25	.40	1.70
2 months	10.29	1.69	.36	2.30	.27	.33	1.49
3 months	8.28	1.38	.33	1.70	.25	.31	.94
4 months	8.02	1.36	.26	1.73	.20	.31	.80
5 months	8.16	1.36	.32	1.78	.22	.31	.93
6 months	8.38	1.40	.26	1.81	.19	.31	.88
7 months	7.82	1.29	.29	1.74	.21	.27	.77
8 months	8.45	1.39	.25	1.96	.19	.25	.71
9 months	8.37	1.45	.26	1.78	.18	.23	.75
10 months	8.03	1.44	.20	1.99	.14	.22	.66
11 months	8.03	1.54	.19	1.82	.13	.21	.62
12 months	7.66	1.52	.16	1.85	.10	.19	.58
13 months	7.77	1.55	.16	1.77	.10	.23	.65
14 months	8.38	1.83	.16	1.72	.12	.24	.80
			DEAD LEAVES				
4 months	11.62	3.28	.59	.46	.35	.21	.29
5 months	8.64	2.16	.42	.56	.28	.20	.26
6 months	8.72	2.19	.39	.60	.25	.25	.26
7 months	8.15	2.05	.41	.71	.27	.26	.27
8 months	8.45	1.97	.38	.88	.27	.24	.22
9 months	8.82	2.16	.43	.81	.27	.16	.21
10 months	8.98	2.44	.41	.79	.25	.14	.22
11 months	8.72	2.41	.35	.81	.21	.14	.18
12 months	8.45	2.37	.30	.90	.16	.10	.18
13 months	7.72	2.39	.29	.53	.14	.12	.18
14 months	8.08	2.61	.25	.64	.14	.13	.13

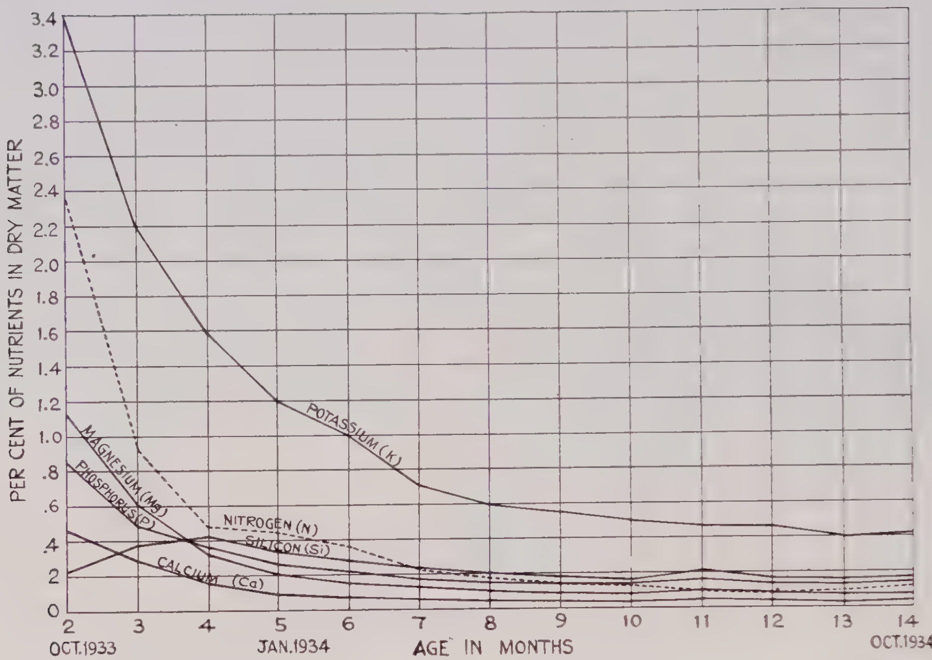

Fig. 2. Showing the changes which occurred with age in the mineral composition of the stalk.

Changes With Age in the Percentage Composition of the Stalk:

The changes which took place in the composition of the stalk as the crop developed were much more pronounced and operated over a longer period of time than the more rapidly maturing leaves. These changes are illustrated in Table II and in Fig. 2. Referring to the figure, it will be observed that the percentages of all elements but silicon decreased consistently up to eight or more months. After reaching a maximum at four months, the percentage of this element likewise decreased. Potassium was less prone than the other elements to reach a constant value and there is reasonable doubt that such a value had been attained, even by the end of the experiment. There seems little question, however, but that the other elements had ceased to decrease by the end of the first year. In earlier, related studies in Hawaii (1, 6), changes in the concentrations of nutrients in the stalk have been observed at ages considerably greater than those at which constant values were obtained in the present experiment. This difference possibly results from the fact that, in the previous studies referred to, samples taken for analysis were so selected as to approximate the composition of the millable cane as a whole and hence contained some stalks younger than the age of the experiment would indicate whereas, in the present investigation, sampling was confined to the original stand of cane.

From the foregoing discussion it is apparent that the mineral compositions, both of the leaves and of the stalk of sugar cane, are very definitely functions of the age of the plant. Hence, if any significance is to be attached to data relating to the mineral composition of the cane plant, it should be done only in view of the age of the plant. This is true whether the composition of the specimen is to be employed

as an index to the nutrient status of the soil, or for comparison with other (normal) specimens, as in physiological or pathological studies.

Translocation of Nutrients in the Leaves:

If a comparison is made of the compositions of the dry matters of the green and dead leaves (see Table II) it will be seen that the former contain much higher percentages of potassium and nitrogen, and generally greater percentages of phosphorus, than the latter. If we may assume that the dead leaves which accumulated between any two periods of harvest were once even roughly similar in composition to the green leaves harvested at the same period, then we have evidence of the substantial translocation of these nutrients from the green leaves back into the stalk. It might be argued that this does not prove translocation, since the mass of green leaves at each harvest contained many young, succulent members which, on a dry-weight basis, would be expected to contain larger proportions of these nutrients than the dry leaves. If this were the correct explanation, we should expect to find the dry matter of the green leaves richer also in such elements as calcium, magnesium, and silicon. The reverse, however, is the case.

In a recent investigation of the composition of the individual leaves of the cane plant, the author found that generally the older the leaf the higher the concentrations (expressed on the dry-weight basis) of silicon, calcium, and magnesium, whereas the reverse was true of nitrogen and potassium. The behavior of phosphorus in this connection was indefinite. From these observations also, the suggestion is strong that large proportions of the nitrogen and potassium contained in the green leaves migrate back to the stalk before the leaves become physiologically inactive. Such migration in the cane plant in the instance of potassium has previously been observed by Boname (3), Hartt (5), and van Houwelingen (7). The last mentioned obtained evidence also of the migration of nitrogen and phosphorus.

Uptake of Nutrients by the Growing Crop:

In the following discussion the demands made upon the soil for plant nutrients by the growing cane crop and the distribution of the absorbed nutrients within the several phases of the crop are considered. The quantities of nutrients and of dry matter contained in the green leaves, dry leaves, stalk and entire plant, at successive ages, are shown in Table III. The data are presented upon the basis of the number of grams of nutrients, and of dry matter, present in a single plant or part thereof. The data are also shown in more readily comprehensible forms in Figs. 3 to 9.

Calcium: Referring to Fig. 3, it will be seen that calcium was taken up by the cane plant at a rate which increased rapidly during the initial stages of growth and which attained a maximum value at the early age of three months. The rate of absorption reached at this point was generally maintained until the age of about nine months when it commenced to diminish. The quantity of calcium contained in the green leaves increased until the age of five months when it became constant. A later decrease in the calcium content of the green leaves was coincident with the slight drop in the rate of absorption already noted. The importance of considering the dead leaves in a study of this type—a factor frequently neglected—is well illus-

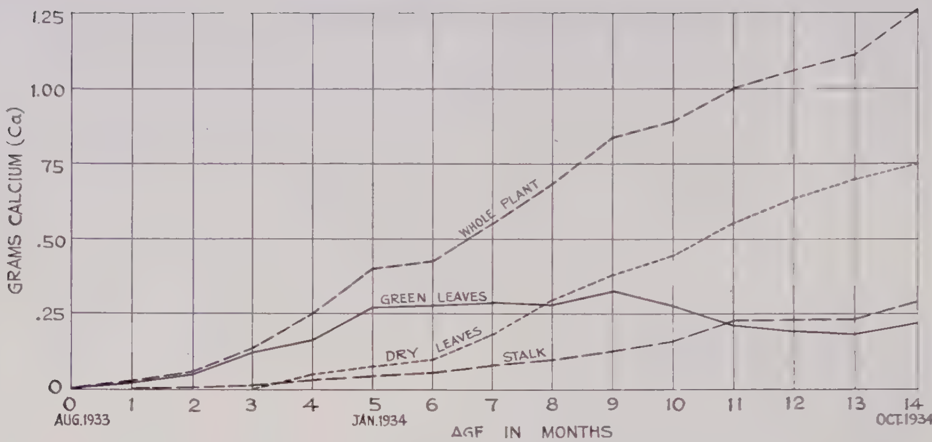

Fig. 3. Showing the rate at which calcium was taken up by the cane plant and the distribution of this nutrient among the several components of the crop.

trated in the present experiment. Referring to Fig. 3, it will be seen that at the final harvest, the accumulated dead leaves contained 1½ times as much calcium as the entire standing crop.

TABLE III

GRAMS OF NUTRIENTS AND OF DRY MATTER CONTAINED IN THE CANE PLANT AT AGES OF FROM 2 TO 14 MONTHS

Age, months	Grams of Si	Ca	K	Mg	P	N	Dry matter
			GREEN LEAVES				
2	0.26	0.054	0.35	0.039	0.050	0.23	15
3	0.51	0.12	0.63	0.093	0.11	0.35	38
4	0.84	0.16	1.06	0.12	0.19	0.50	62
5	1.14	0.27	1.49	0.18	0.26	0.77	84
6	1.49	0.28	1.93	0.21	0.33	0.94	107
7	1.34	0.29	1.79	0.21	0.28	0.80	104
8	1.56	0.28	2.21	0.21	0.29	0.81	112
9	1.84	0.33	2.26	0.23	0.29	0.95	127
10	1.99	0.28	2.75	0.19	0.30	0.93	138
11	1.73	0.21	2.05	0.15	0.24	0.70	113
12	1.77	0.19	2.16	0.12	0.22	0.68	117
13	1.74	0.18	1.98	0.12	0.25	0.73	112
14	2.47	0.22	2.32	0.17	0.33	1.09	135
			DRY LEAVES				
4	0.29	0.050	0.042	0.030	0.020	0.025	8.8
5	0.43	0.079	0.079	0.048	0.033	0.040	15
6	0.57	0.10	0.12	0.066	0.050	0.060	22
7	0.95	0.18	0.25	0.11	0.098	0.11	40
8	1.60	0.30	0.53	0.20	0.17	0.18	73
9	2.04	0.38	0.70	0.26	0.21	0.22	93
10	2.46	0.45	0.83	0.30	0.23	0.26	110
11	3.22	0.56	1.09	0.36	0.28	0.32	142
12	3.81	0.64	1.32	0.40	0.30	0.36	167
13	4.33	0.70	1.43	0.43	0.33	0.40	188
14	4.79	0.75	1.56	0.46	0.35	0.43	208

Age, months	Si	Ca	K	Grams of Mg	P	N	Dry matter
				STALK			
2	...	0.004	0.012	0.006	0.004	0.010	0.4
3	0.016	0.011	0.091	0.024	0.020	0.040	4.2
4	0.091	0.036	0.35	0.072	0.081	0.11	22
5	0.16	0.046	0.59	0.10	0.13	0.22	49
6	0.24	0.054	0.85	0.13	0.19	0.30	85
7	0.34	0.082	1.00	0.18	0.25	0.32	130
8	0.45	0.10	1.34	0.24	0.34	0.41	229
9	0.55	0.13	1.70	0.30	0.43	0.48	312
10	0.72	0.16	2.14	0.34	0.62	0.54	425
11	0.97	0.23	2.15	0.45	0.77	0.48	471
12	1.11	0.23	2.86	0.45	0.92	0.61	579
13	1.07	0.23	2.59	0.46	0.88	0.64	649
14	1.33	0.29	3.20	0.58	1.05	0.89	765
				WHOLE PLANT*			
2	0.26	0.058	0.36	0.045	0.054	0.24	16
3	0.53	0.13	0.72	0.12	0.13	0.39	42
4	1.22	0.25	1.45	0.22	0.29	0.63	93
5	1.73	0.40	2.16	0.33	0.42	1.03	148
6	2.30	0.43	2.90	0.41	0.57	1.30	214
7	2.63	0.55	3.04	0.50	0.63	1.23	274
8	3.61	0.68	4.08	0.65	0.80	1.40	414
9	4.43	0.84	4.66	0.79	0.93	1.65	532
10	5.17	0.89	5.72	0.83	1.15	1.73	673
11	5.92	1.00	5.29	0.96	1.29	1.50	726
12	6.69	1.06	6.34	0.97	1.44	1.65	863
13	7.14	1.11	6.00	1.01	1.46	1.77	949
14	8.59	1.26	7.08	1.21	1.73	2.41	1,108

* Green leaves, dry leaves and stalk.

Magnesium: Absorption of magnesium by the cane plant as a whole practically paralleled that of calcium at all stages of growth, as may be seen by a comparison of Figs. 3 and 4. A marked distinction appears, however, in the distribution of these two nutrients within the plant. Thus, at all stages of growth, much larger proportions of the absorbed magnesium than of calcium were present in the stalk. Conversely, larger proportions of calcium than of magnesium were contained in the leaves.

Phosphorus: Reference to Fig. 5 will show that absorption of phosphorus was relatively slight during the initial three months of growth. Less than 10 per cent of the quantity absorbed in the course of the first year was taken up during this period. Subsequently, phosphorus was absorbed by the cane plant at an increased rate which remained practically constant until the conclusion of the experiment. This finding supports, in part, that of an earlier investigation (1) in which it was similarly found that phosphorus was taken up by the cane crop at a rate which was essentially constant after the initial three months of growth. As in the case of magnesium, there was no increase in the content of this nutrient in the green leaves after six months.

Phosphorus was found to be present in the stalk to a relatively greater extent than were any of the other nutrients studied. More than half of the absorbed phos-

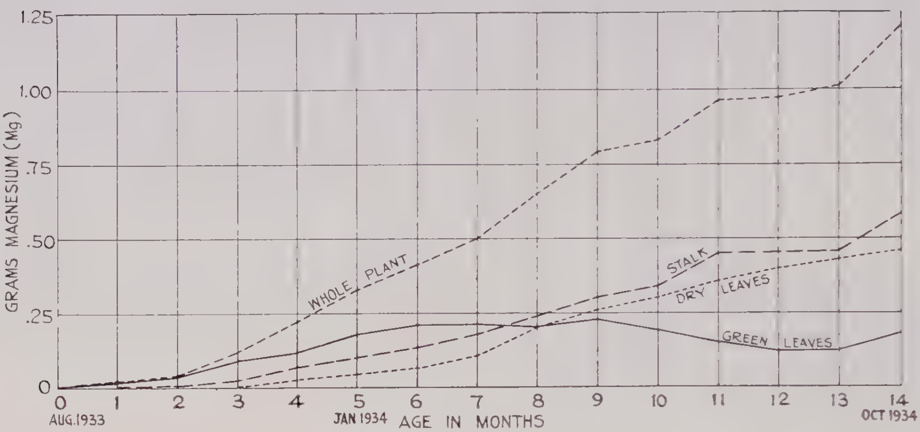

Fig. 4. Magnesium was absorbed at practically the same rate as calcium. The distribution of these two nutrients among the stalks, green leaves and dry leaves, however, was very different.

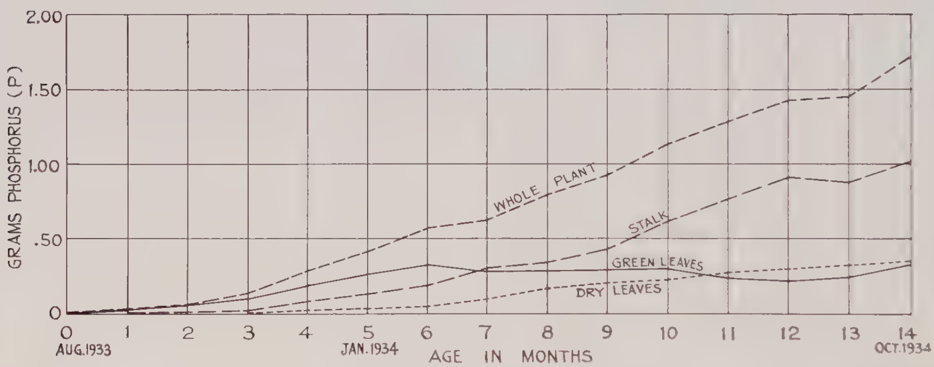

Fig. 5. Showing the rate at which phosphorus was taken up by sugar cane. Phosphorus was found to be present in the stalk to a greater degree than were any of the other elements for which analysis was made.

phorus was present in this organ of the plant after the age of seven months. Since the tops and trash normally remain in the field at harvest, it is the quantities of nutrients present in the stalk which measure the permanent loss of a nutrient to the field through cropping.*

Silicon: Reference to Fig. 6 shows that absorption of this constituent of the ash was very rapid following the first three months of growth, reaching, at seven months, a rate which remained practically constant throughout the remainder of the experiment. In contrast to the cases previously considered, the silicon content of the green leaves did not reach a maximum until the age of 10 months. Only a small proportion of the silicon absorbed by the cane plant was found in the stalk at any period of harvest. At the final sampling (14 months) it amounted to but 15 per cent of the total taken up. Thus, although sugar cane takes up very large quanti-

* An exception to this statement must be noted in the case of nitrogen, since a large proportion of the nitrogen contained in the tops and in the trash is lost through preharvest and postharvest burnings.

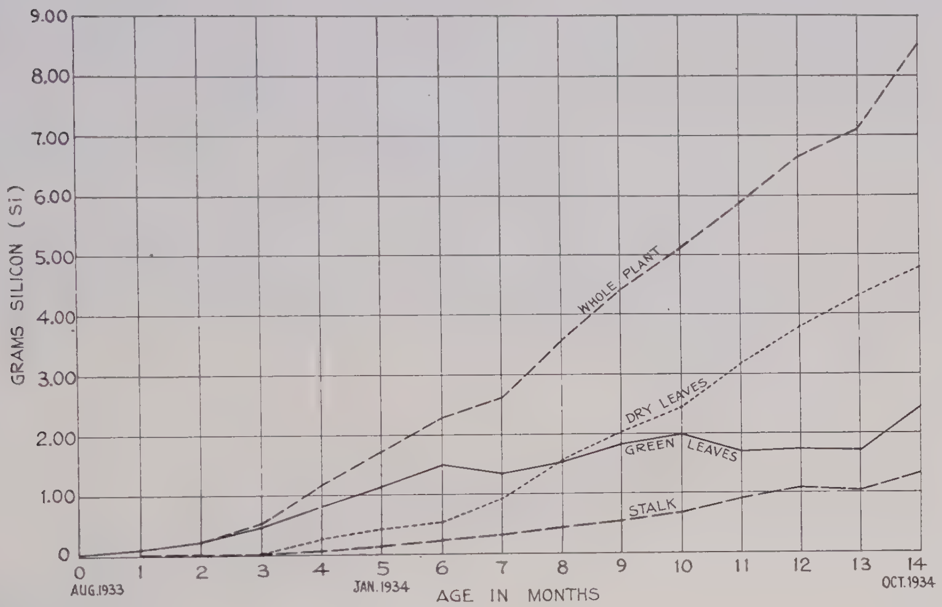

Fig. 6. Silicon was taken up in larger amount than any other mineral element. Relatively little silicon remained in the stalk. Most of it passed through to the leaves, where it was lost to the plant as the older leaves died and were cast off.

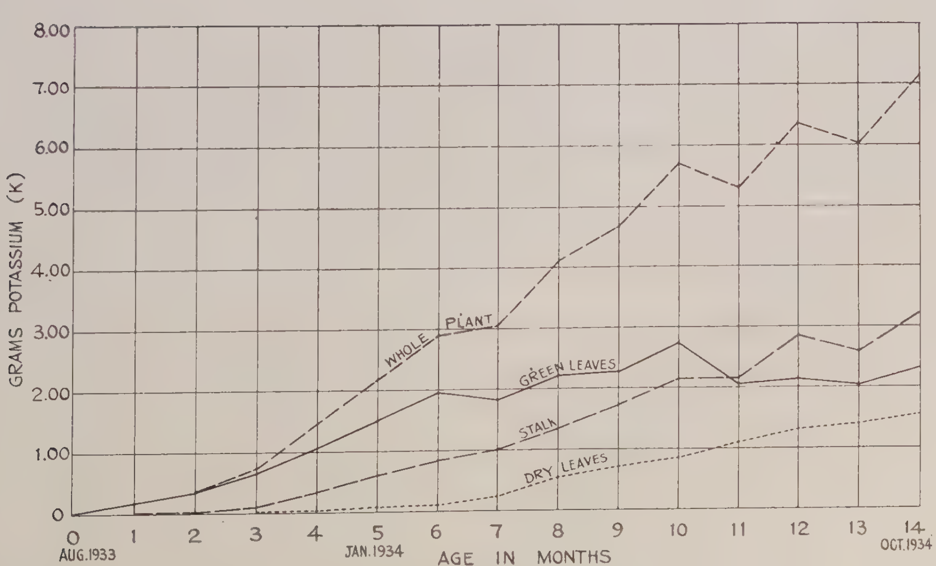

Fig. 7. This graph shows the rate at which the sugar cane absorbed potassium. The distribution of this nutrient among the several components of the crop is also shown.

ties of silicon, relatively little is permanently lost to the field through cropping. As in the case of calcium, more silicon was present in the accumulated dead leaves at the final harvest than in the entire living crop.

Potassium: Referring to Fig. 7, it will be seen that the rate of absorption of potassium by the cane plant, like that of most of the other nutrients considered, attained a maximum at the age of three months. During this period only 11 per cent of the first year's uptake of the nutrient occurred. The rate reached at this point was generally maintained until the age of 10 months, when it commenced to diminish. It will be observed that this reduction in the absorption of potassium by the plant coincided with the acquirement by the green leaves of their maximum content of the nutrient. Or, to state it in the reverse manner, the reduced need of the leaves for potassium was reflected in diminished absorption of the nutrient. Potassium was present in the stalks of the older canes in relatively smaller degree than was phosphorus. Hence, loss of potassium from the soil through cropping would be proportionately less than in the case of phosphorus.

The findings of this investigation relative to absorption of potassium by the plant are generally in harmony with those of Stewart (6) who found that this nutrient was taken up very rapidly by sugar cane between the ages of three and eight months, but at a much slower rate during the remainder of the first year. In a later investigation (1), potassium was found to be absorbed at a rapid rate between the ages of three and 12 months, but at a greatly reduced rate after 12 months. Work now in progress in this laboratory indicates that the demand made upon the soil for potassium by the variety of cane grown in this experiment (H 109) is greatly exceeded by that of certain other varieties.

Referring to Fig. 9, in which is shown the growth of the cane plant, as measured by the formation of dry matter, it will be observed that an era of rapid growth began at about the age of seven months and continued until the end of the experiment. It might be expected that the commencement of this period of enhanced development would mark a corresponding increase in the uptake of potassium. Referring to Fig. 7, it will be seen that this was not the case. Moreover, while the absorption of potassium diminished after the tenth month, as has been pointed out, there was no corresponding diminution in the rate of growth of the cane plant. Hence, it appears that *the rate at which potassium is absorbed by sugar cane is not primarily a function of the rate of growth, but of the age, or of the stage of development of the plant.* This appears to be true of other elements also, particularly calcium, magnesium, and nitrogen.

Nitrogen: The rapid rate at which nitrogen was absorbed during the first three months of growth contrasts strikingly with the relatively much slower uptake of the other nutrients studied. Nearly one-quarter of the nitrogen absorbed in the course of the entire first year was taken up during the initial three months of growth. Absorption of nitrogen continued at a rapid rate until the age of six months was reached, when it generally diminished. A sharp increase in the uptake of this nutrient between 13 and 14 months was coincident both with an application of ammonium sulfate to the experimental area and with the preparation of the plant to tassel. Interpretation of this abrupt rise in the rate of absorption in the last month of the experiment is complicated by the possibility that both of these factors were involved. It appears probable, however, that the ammonium sulfate added at

the age of 13 months was largely, if not wholly, responsible for the subsequently increased rate of absorption of nitrogen. As in the case of phosphorus and certain other nutrients, the quantity of nitrogen in the green leaves did not increase after the age of six months.

With the nutrients previously considered, we have assumed, upon the basis of our analysis of the soil, that at all periods of growth substantial quantities of these substances were available to the crop. In the case of nitrogen, however, we cannot safely make such an assumption. Particularly is this true in view of the increase in the absorption of this nutrient following its application to the soil at 13 months. From the work of Das and Cornelison (4), and from the more recent studies of Q. H. Yuen (at this Station) and of the author, it appears probable that the sharp reduction in the rate of absorption of nitrogen at six months was associated with an abrupt and marked lowering of the supply of available soil nitrogen at that point. It is probable, therefore, that the uptake of nitrogen by the plant between the ages of 6 and 13 months (when ammonium sulfate was added) does not represent the maximum absorption of which the plant was capable.

Whatever the cause of the reduced uptake of nitrogen at this comparatively early age of the crop, there was no corresponding effect upon the growth of the plant, as will be seen by a comparison of Figs. 8 and 9. In fact, the maximum rate of growth of the crop did not obtain until shortly *after* the absorption of nitrogen began to fall off. Moreover, growth continued at this maximum rate throughout the succeeding seven months or until the conclusion of the experiment.

As will be seen by reference to Table II, the continued normal growth of the plant, under conditions of reduced uptake of nitrogen, was associated with a greater nitrogen economy in subsequently formed leaves and stalk, that is, until nitrogen was again applied at 13 months. There was also some evidence that nitrogen which entered the stalk during the period of rapid uptake of the element was subsequently reutilized in the formation of new tissue.*

Further evidence that the cane crop takes up the bulk of its nitrogen during the early months of growth is shown by the results of an experiment conducted at Oahu Sugar Company, Ltd. (1927-1929). Relative to the uptake of nitrogen by the crop, Stewart (6) states, "By the eighth month of the crop's growth . . . all the plots had taken up the largest part of the crop's total supply of nitrogen. There was a further gradual abstraction, but the most rapid absorption took place in the early months of the growth of the crop." In this experiment a little more than 2/3 of the total amount of nitrogen received by the crop was applied during the first six months of growth. A most striking example of the ability of the cane plant to continue the production of millable cane over a period of months without further appreciable uptake of nitrogen is provided in an experiment conducted at the Waipio substation 1928-29 (1). In this experiment, in which all of the nitrogen was applied during the first six months of growth, the crop at 24 months apparently contained no more nitrogen than at 12 months. Yet, the yield of millable cane increased during that period from a little over 50 tons to nearly 100 tons.

It appears, therefore, that what was found to be true of potassium and certain other elements is even more true of nitrogen, namely, that the rate of uptake of

* See "Translocation of Nutrients in the Stalk" in this paper.

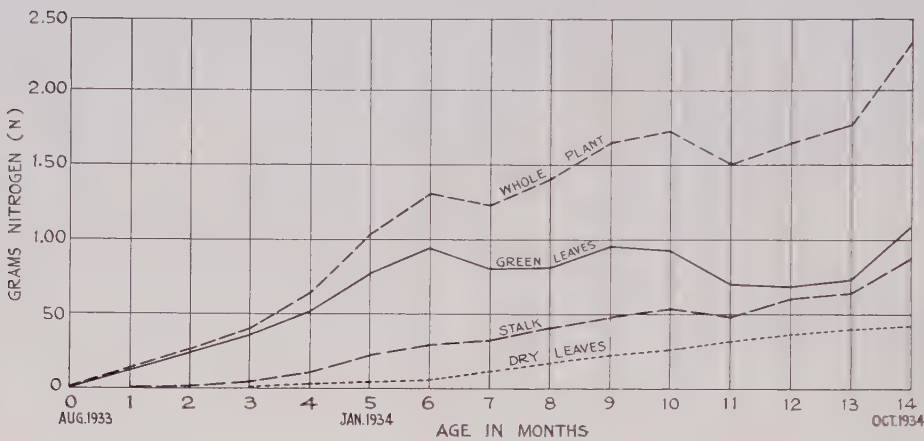

Fig. 8. Nitrogen was taken up very rapidly during the first six months of growth. From this point, until the age of 13 months was reached, and during which no nitrogen fertilizer was added, absorption was relatively slight. Rapid uptake of the nutrient followed fertilization with nitrogen at 13 months.

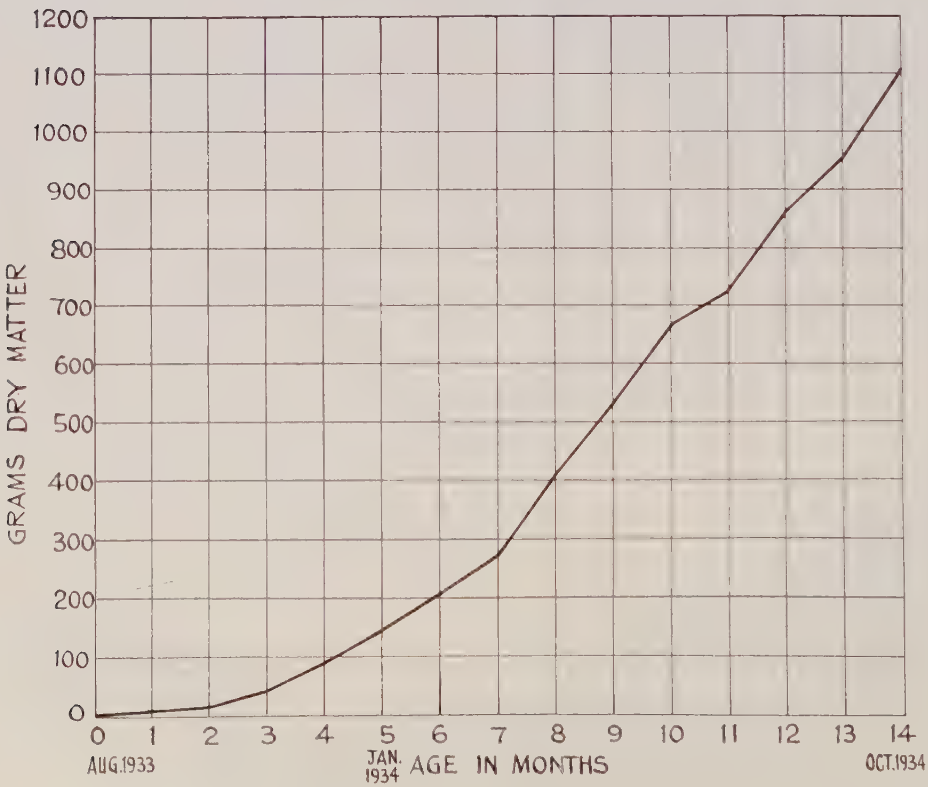

Fig. 9. Showing the growth of the cane plant as measured by the increase in total dry matter.

nitrogen by sugar cane, at least under the conditions of limited supply usually present in the field, bears little relation to the rate of growth of the crop. Rather does the plant absorb nitrogen very rapidly during the early months of growth, or until the leaves and the green-leaf portion of the stalk, which are rich in nitrogen, have become well established. Following the attainment of this stage of development, very much smaller quantities of the nutrient apparently suffice to carry the crop to maturity. In this connection it will be recalled that much of the nitrogen contained in the green leaves migrates back to the stalk before the leaves die. The subsequent reutilization of this nitrogen doubtless enables the crop to grow with a lower uptake of nitrogen than would otherwise be required.

Distribution of Nutrients in the Stalk:

An interesting picture of the manner in which the mineral nutrients are distributed throughout the length of the stalk is given in Fig. 10. The heights of the columns shown in the chart represent the quantities of nutrients in successive three-foot sections of the stalk. Referring to the figure, it will be seen that calcium is fairly evenly distributed throughout the 12-foot length of stalk there represented. To a slight extent, the quantities of nitrogen, and in a very marked degree, those of magnesium, phosphorus, and silicon increase per unit length of stalk as the base of the stalk is approached. With potassium, exactly the reverse is the case, the

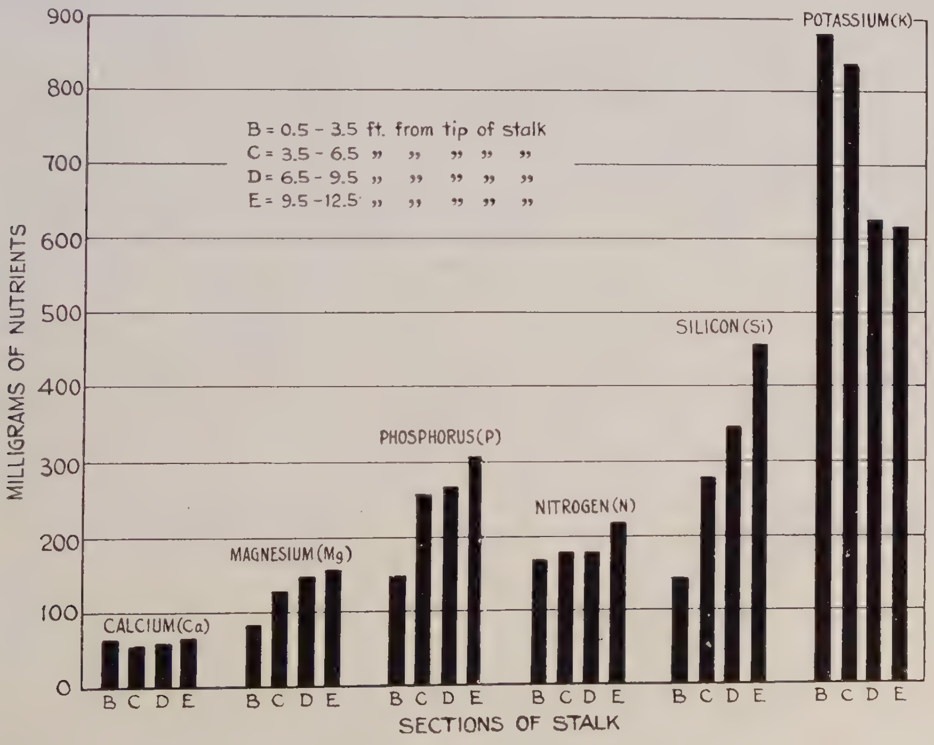

Fig. 10. This chart shows the distribution of nutrients in successive three-foot sections of the stalk of sugar cane at the age of 14 months. It will be noted that potassium decreases as the base of the stalk is approached, whereas the other elements tend to increase.

amount of this nutrient per unit length of stalk being greatest in the upper portion of the stalk where cellular activity is at a maximum.

Translocation of Nutrients in the Stalk:

Periodic examination of the total quantity of a nutrient in a definite portion of the cane stalk makes it possible to determine whether or not any changes are occurring in the nutrient content of that portion of the stalk as the plant develops. This was done in the present investigation by comparing the amounts of nutrients contained in three-foot segments of stalk formed during the early months of the experiment with corresponding sections (that is, formed during the same period) harvested later in the experiment. While the data pertaining to this matter are not as extensive as might be desired, they appear to indicate that as the younger tissues of the stalk mature they lose nitrogen and potassium through the upward migration of these nutrients. This movement was more pronounced in the case of potassium than in that of nitrogen. In contrast, silicon and phosphorus were found to accumulate as the tissue became older. Neither translocation nor accumulation of either calcium or magnesium in the stalk was observed. Translocation of potassium in the stalk of the cane plant has previously been observed by Boname (3), by the author (2) and by others.

Summary

A study has been made of changes which occur with age in the mineral composition of the sugar cane plant and of the uptake of the several nutrients with respect to the age of the crop.

It was found that the percentage compositions of the leaves and of the stalk of the cane plant are markedly influenced by the age of the plant, particularly during the early months of growth. Hence, the indiscriminate utilization of data pertaining to the percentage composition of the cane plant may prove fallacious.

The dry matter of dead cane leaves was found to contain much lower concentrations of potassium and nitrogen, and somewhat lower percentages of phosphorus than that of green leaves. This is accounted for on the basis that these nutrients migrate from the leaves back to the stalk before the leaves become physiologically inactive.

The cane plant was found to absorb the principal mineral nutrients in widely different amounts. Potassium and silicon were taken up to the greatest extent, while nitrogen and phosphorus were absorbed in relatively moderate quantities. Of the nutrients studied, calcium and magnesium were absorbed in least amount.

The rates at which the several mineral nutrients were absorbed were found to vary with the age of the plant, but not always in the same degree for each nutrient. The rates of absorption of all the elements studied, with the exception of silicon, reached maximum values by the early age of three months. During this period approximately 10 per cent of the first year's uptake of phosphorus and potassium occurred. The corresponding quantity of nitrogen was much greater, amounting to nearly 25 per cent. After the age of six months, in the case of nitrogen, and after about 10 months, in the cases of calcium, magnesium, and potassium, the rates of absorption diminished. Uptake of silicon and phosphorus, on the other hand,

continued at essentially constant rates until the conclusion of the experiment at 14 months.

The rates of absorption of potassium and nitrogen were found to decrease immediately following the acquirement of maximum quantities of these nutrients by the green leaves.

From the results of this study it is apparent that absorption of nitrogen and potassium, and in less marked degree, that of certain other nutrients, by sugar cane is not primarily a function of the rate of growth, but of the age, or of the stage of development, of the plant.

Pronounced differences were found in the distribution of the elements among the components of the crop. These differences were most marked in the instances of phosphorus and silicon. The quantities of these nutrients in the stalk (at the final harvest) amounted to 60 and 15 per cent, respectively, of the totals taken up by the plant.

Periodic examination of the quantities of the several nutrients contained in given segments of the stalk indicates that as the younger tissues of the stalk mature they lose potassium and nitrogen through the upward migration of these nutrients.

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Chemical Analyses as an Aid in the Control of Nitrogen Fertilization

By Q. H. Yuen and R. J. Borden

Foreword

Soil analysis as one of the aids to the fertilization of Hawaiian soils for sugar cane culture has been simplified somewhat by rapid chemical analytical methods. Due to the ease and rapidity with which determinations may be made, many of the soil testing assemblies developed at the Experiment Station have been widely adopted for use on plantations by resident agriculturists and other workers.

Of the several major R.C.M. (rapid chemical methods) soil testing assemblies, the soil phosphate and soil potash units, which are in general use, have made it possible to correlate data in R.C.M. soil studies with those obtained in other soil chemical investigations and also with Mitscherlich soil tests and field experiments. These correlations have been used as guides in fertilization of many plantation soils with phosphate and potash.

Following requests for a simplified procedure whereby the available nitrogen in soils may be evaluated in a manner similar to the R.C.M. determinations of phosphate and potash (with corresponding analytical equipment) the chemistry department of the Experiment Station has developed (among others) a method and assembly for the rapid estimation of ammonia and nitrate nitrogen in soil (16, 17). The sum of these two forms of soluble nitrogen, when thus determined, is taken as a measure of the concentration of the nitrogen in the soil which is available at the *moment* of analysis.

In order to augment a none too thorough understanding of the practical application of soil nitrogen data accruing from rapid chemical analyses, and to acquire additional information from studies employing this newer method of analysis, further researches have been made by Q. H. Yuen and R. J. Borden upon the availability status of nitrogen in Hawaiian soils and the nitrogen phase of soil-plant relationships. Supplementing investigations conducted on plantations by individual agriculturists, the agricultural and chemistry departments of the Experiment Station have cooperated in conducting a number of pot experimental studies at Makiki, the results of which are presented in this paper.

F. E. Hance.

The present study embraces two aspects of the nitrogen problem: the soil variations and the soil-plant relationships. The soil studies include measurements of the rates of nitrification and of the variability in the amounts of available nitrogen under conditions both with and without plant growth. The pot experiments with cane and other crops were designed and conducted to yield information relevant to the absorption of nitrogen by the crop, and to the relation of known nitrogen fertilization to yield and crop composition.

A review of the literature has indicated that numerous local studies on diverse phases of the nitrogen problem have been made which have yielded data and information of a fundamental nature. The biochemical aspects have received the attention of Peck (28, 29, 30), McGeorge (25) and Heck (18), who investigated the effect of the addition of molasses on the availability of soil nitrogen and upon nitrification in Hawaiian soils. Kelley (19), Burgess (7) and McGeorge (23, 24) have reported studies based upon the nitrification processes as a measure of soil fertility. The retention of nitrates by Hawaiian soils has been investigated by Stewart and Hansson (34). The loss of nitrates by leaching from fallow pineapple soils has been discussed by Magistad (22). The relation between nitrogen and organic matter has been made the subject of investigational research by Dean (9). Studies of the relation of nitrogen fertilization to the yield and composition of the cane crop have been reported by Alexander (2), Ayres (4, 5) and Das and Cornelison (8).

Experimental

Methods of Analyses:

The rapid chemical method (R.C.M.) for the determination of available nitrogen in soils is described by Hance (16) as one which consists of extracting a measured amount of soil with a dilute aqueous solution of potassium sulfate. By the process of base replacement and water solution, the ammoniacal and nitrate nitrogen are obtained in the extract. The two forms of nitrogen are determined in separate aliquots by colorimetric methods.

Total nitrogen in soils and plant materials was determined respectively by the official Gunning method and the Gunning method modified to include the determination of nitrate nitrogen (3).

Pot Tests:

The Mitscherlich pots and technic were used since these eliminated the factor of loss of nutrients by leaching. In all cases, to both the cropped and uncropped soils, water was applied in moderate amounts. When an excess was required, as in the case of plants reaching maturity, the drainage or leachate was returned to its respective pot. Where sugar cane was the crop grown, plantings of two shoots per pot were made from one-eye cuttings of seed pieces germinated in sand boxes and started for a period of four weeks before transplanting. Sudan grass plantings were made directly from seeds and the seedlings were thinned soon after appearing above ground to leave 40 plants in each pot.

Soil Studies

Incubation Tests (soils without crop):

Incubation tests were conducted by placing in Mitscherlich pots 4½ kilograms of air-dry soils to which were added in solutions, 9 grams P_2O_5 from superphosphate and 1½ grams K_2O from potash sulfate. When nitrogen was supplied, this nutrient was applied from an ammonium nitrate solution. All fertilizers were mixed into the soil before potting. Soil samples were taken periodically from these uncropped pots and determinations of available nitrogen in the moist soils were made by the

rapid chemical methods of analysis. The soils were extracted and analyzed the same day on which the samples were taken, thereby eliminating the fluctuations which may occur in soil-nitrogen relationships upon soil storage. In this manner a periodic measure of available nitrogen status of the soil without the interfering factors of plant growth and loss by leaching was secured. Fluctuations were investigated where gains and losses of nitrogen were indicated as the result of nitrification and seasonal changes. Studies were made of the nitrification of added nitrogen from ammonium nitrate, as well as of the original nitrogen in the soils; in both cases ample fertilization with phosphate and potash was given.

Nitrification

Reviewing, briefly, recognized truths established by other investigators, it may be stated: When either ammoniacal or organic nitrogenous fertilizer is applied to a soil, the nitrogen thus added is gradually converted to the inorganic nitrate (or nitric) form. This process is known as nitrification. Conversely, when nitrate is reduced or changed to the gaseous oxides of nitrogen, or to the ammoniacal form, the process is known as denitrification. Soils vary individually in their capacities to support these changes.

Occurrence in Acid Soils:

Nitrification occurs readily in neutral soils. While nitrification is known to proceed in acid soils, it has often been assumed that the process is suppressed in such soils. From the standpoint of learning what happens to ammoniacal nitrogen when it is applied to an acid soil, it was considered desirable to make nitrification studies on such soils. Two acid soils were selected; one of these was a surface soil from Manoa Field 22 which had a pH of 5.8 and the other, a surface soil from Hamakua Field 27K with a pH of 5.5. Ammonium nitrate, supplying equal amounts of ammoniacal and nitrate nitrogen, was added to these soils.

Data obtained from these incubation experiments are submitted graphically in Figs. 1, 2, 3, and 4. The results indicate that active nitrification has occurred in these acid soils. It will be noted that, following the nitrification of the added nitrogen, very little ammoniacal nitrogen was found in any of the soils during the entire incubation period.

Time Required to Reduce the Ammoniacal Nitrogen Level:

During the process of oxidation of ammonia to nitrate, the ammoniacal nitrogen level is gradually reduced and nitrate tends to increase correspondingly as oxidation reaches completion. However, a lag may occur following the lowering of the ammonia level before the nitrate analysis is shown to increase, the degree of the lag depending, perhaps, on the speed with which the various steps of oxidation can be completed. Aside from considerations of its removal by microorganisms in processes other than nitrification, or of losses by chemical reaction, and since loss by leaching is not a factor in these experiments, any lowering of the ammoniacal nitrogen level in this uncropped soil may be assumed to indicate nitrification activity. This assumption has been supported by increases of the nitrate levels which follow the

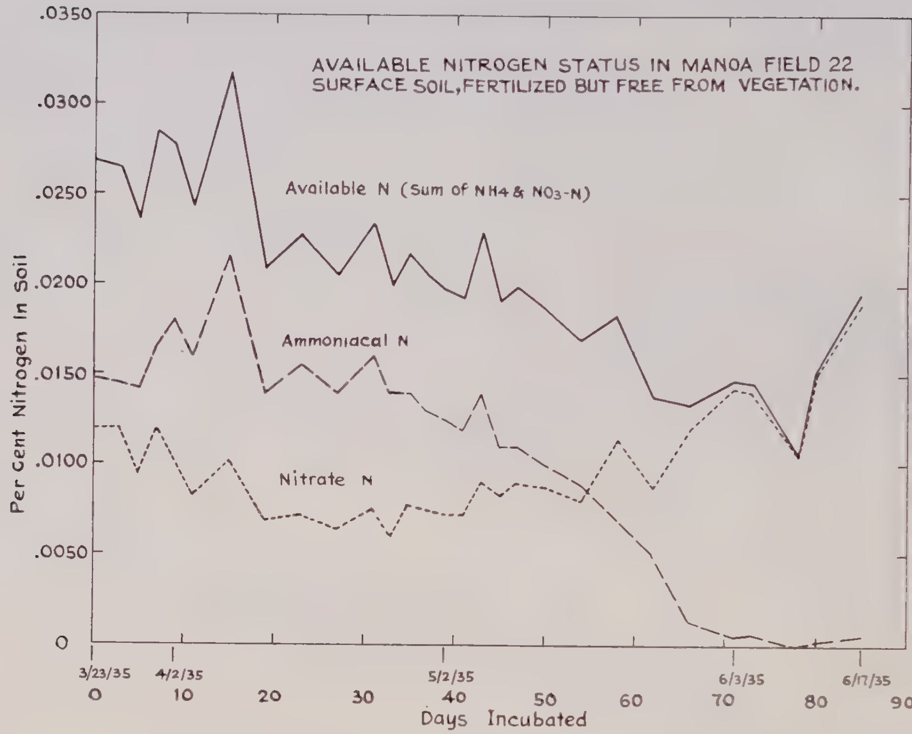
AVAILABLE NITROGEN STATUS IN MANOA FIELD 22
SURFACE SOIL, FERTILIZED BUT FREE FROM VEGETATION.
Available N (Sum of NH4 & NO3-N)
Ammoniacal N
Nitrate N
Per Cent Nitrogen In Soil
.0350
.0300
.0250
.0200
.0150
.0100
.0050
0
3/23/35
4/2/35
5/2/35
6/3/35
6/17/35
0
10
20
30
40
50
60
70
80
90
Days Incubated

Fig. 1

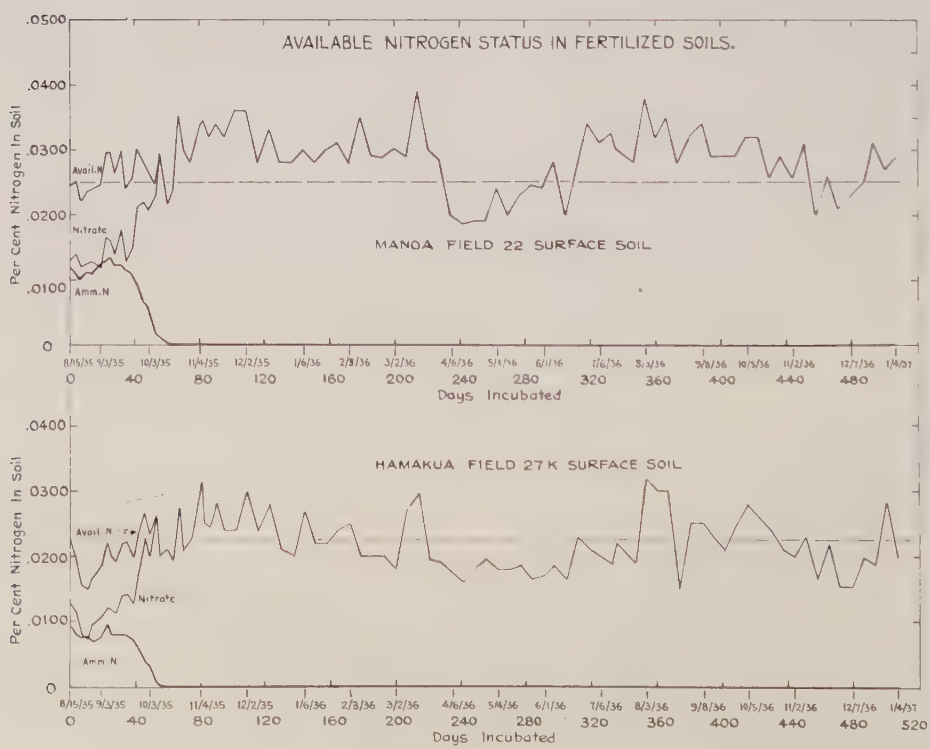
AVAILABLE NITROGEN STATUS IN FERTILIZED SOILS.
MANOA FIELD 22 SURFACE SOIL
Avail. N
Nitrate
Amm. N
Per Cent Nitrogen In Soil
.0500
.0400
.0300
.0200
.0100
0
Days Incubated
HAMAKUA FIELD 27 K SURFACE SOIL
Avail. N
Nitrate
Amm. N
Per Cent Nitrogen In Soil
.0400
.0300
.0200
.0100
0
Days Incubated

Fig. 2

depletion of ammonia. Therefore, for practical purposes, the time interval required to deplete ammoniacal nitrogen may be considered as the time required to nitrify the ammoniacal nitrogen which was added to the soil in the incubation pots under consideration.

In the initial (March) test with the Manoa soil (Fig. 1), a period of 78 days was required for the nitrification of the added ammoniacal nitrogen. The ammoniacal nitrogen content of the soil was 0.0148 per cent following the addition of 1.1 grams of nitrogen from ammonium nitrate (one-half of which is in the ammoniacal form) to each pot (4½ kilograms of soil). At the end of 78 days, the ammonia level in this soil had reached zero, as indicated by soil analysis. The second test with this soil (Fig. 2), receiving the same treatment, but started some 5 months later (in August), gave results which showed that nitrification required only 63 days. This same soil, without any nitrogen fertilization, required but 50 days for the depletion (Fig. 3) of its ammoniacal nitrogen when the initial level in the soil was 0.0015 per cent. Thus, it will be seen that the time required for nitrification may be variable for the same soil receiving the identical treatments, but started in different periods of the year (Figs. 1 and 2).

While it may not be comparable, for the reason that the soils are not identical, an incubation test started in May with another Manoa soil collected from an adjoining field showed an interval of only 35 days required to nitrify 0.75 gram of added ammoniacal nitrogen when the initial level was 0.0175 per cent ammoniacal nitrogen (Fig. 4).

A graph showing the status of the inorganic nitrogen throughout the incubation period for the Hamakua soil is presented in Fig. 2. Nitrification is found to occur readily in this soil under the environmental conditions found at the Makiki station. Started at the same time as the second test of the Manoa soil (in August), and receiving identical fertilizer treatments, a period of 56 days was required for the nitrification of its ammonia. This is one week less than the 63 days indicated for the Manoa soil incubation started at the same time.

Recovery: Loss and Gain of Available Nitrogen During Nitrification:

In many of our local investigations the disappearance of available nitrogen under field conditions is usually ascribed to loss through leaching and by uptake by the growing plants. Little consideration has been given to still another loss which is not accounted for by either leaching or plant absorption. The loss of nitrates following the incorporation of carbonaceous matter (especially molasses) in soils is often explained as being "immobilized" by microorganisms, with the inference that as their death and subsequent decomposition proceeds this nitrogen will become available again through nitrification. The quantitative studies by Lipman and his associates (20, 21) of the New Jersey tank experiments have indicated that loss of nitrogen from soil by means other than leaching and plant absorption may occur in considerable magnitude. Similar observations from field experiments have been made by English investigators. The results of many field experiments and lysimeter studies by American workers have been published which report findings of a corresponding nature.

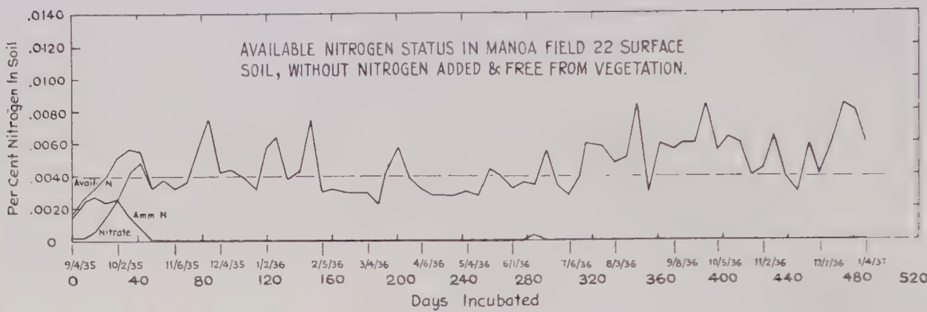

Fig. 3

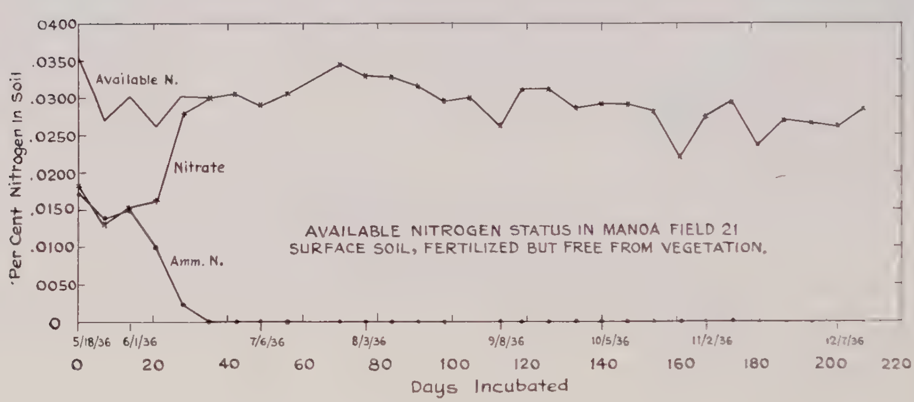

Fig. 4

A gradual loss of available nitrogen throughout the period of incubation in the first test with the uncropped Manoa soil is evident from an examination of the graphs in Fig. 1. Whether this nitrogen had disappeared from the soil or had been merely "tied up" with the organic fraction of the soil or in the microorganisms remains to be definitely established. Plants (Sudan grass) grown in this soil during the same period and with identical fertilization were harvested and analyzed. The nitrogen recovered in these plants, as shown by analyses, was not equal to the amount added. The difference between the theoretical amount which should have been found and that which was actually recovered at the period of their maximum plant-nitrogen content was approximately equal to that which was indicated as lost from the uncropped, similarly fertilized soil. While it was not shown that the loss of available nitrogen was permanent, its removal was at least established in that it was unavailable for plant growth during the period under test.

A study of Fig. 1 is of interest. It will be noted that during the first two weeks of incubation following nitrogen fertilization there was a slight denitrification which was accompanied with a corresponding rise in the ammonia level. From the fifteenth day on, there was a lowering of the nitrate level and a maintenance of this lowered level for an additional 3 weeks or until the eighth week of incubation; meanwhile the ammonia level was gradually declining. From the eighth week on, the drop in the ammonia was accompanied by a rise of the nitrate level. However, at

the end of this first test, on the eighty-fifth day of incubation, the sum of available nitrogen had never reached its level as found at the start of the experiment. Hence, it may be inferred that the nitrification of the added nitrogen fertilizer may not necessarily proceed quantitatively with 100 per cent efficiency.

In some respects the results obtained in the above test may be compared with those reported by Eggleton (13) of the Jealott's Hill Agricultural Research Station, working with English soils. To study the distribution of nitrogen during the process of oxidation of ammonia to nitrate, nitrogen from sulfate of ammonia, from ammonium nitrate and from nitrate of soda was added to soils at the rate equivalent to 88 parts per million of ammoniacal nitrogen (0.0088 per cent). In addition to the treated soils, he had a control series. The soils were kept moist and aerated; the experiment ran for 5 weeks. Every weekday during this period two jars of soil were taken from each series and analyzed for ammonia, nitrate, nitrite, and albuminoid nitrogen. This study showed that the mean recovery in terms of ammoniacal plus nitrate nitrogen for the first week was only 91 per cent of the nitrogen originally added in the ammoniacal form. During the second week the recovery improved to 92.6 per cent; the third week it was 94.8 per cent and in the fourth week, 99 per cent. About 10 per cent of the nitrogen added directly as nitrate was not recoverable within the first two days. Subsequently the recovery averaged 100 per cent. However, recoveries were not as good during the last week of the experiment. Nitrite nitrogen was not found and albuminoid nitrogen was negligible. Three possible causes of this loss are advanced: incomplete extraction, immobilization by microorganisms and the existence of the nitrogen in a form escaping detection. The possibility of loss in the gaseous form through chemical reaction was considered but was discounted.

While a 100 per cent recovery of the added nitrogen was not obtained in the initial test with the Manoa acid soil, an examination of the Manoa and Hamakua soils in Fig. 2 will show that for the second set of experiments the available nitrogen status had attained the original levels after the twentieth and fortieth day of incubation, respectively. It will be noted that a loss of nitrogen had occurred during this initial period. For the other test with a Manoa soil started the following summer (Fig. 4), a loss of available nitrogen occurred which was not made up until about two months later. The recovery was temporary, as a decline immediately set in which persisted for approximately five months, the remaining period of the experiment.

Fluctuations Between Sampling Periods:

An examination of any of the nitrogen graphs in Figs. 1, 2, 3, and 4 will reveal considerable fluctuation in values between sampling periods. Thus, analysis of a sample obtained one day may not necessarily be the same for another sample taken several days later. However, it will be further seen that the fluctuations range within rather definite levels. In other words, the fluctuations do not occur, say, from a high to an extremely low level, or vice versa, between sampling periods of short duration. Thus, if certain levels are established, the available nitrogen status will probably fluctuate within the level attained at equilibrium. Therefore, in spite of the variable nature of the nitrogen value determined at the moment, it can be of

practical use if used in conjunction with its relative fertility level and a factor which will take care of the expected fluctuations between sampling. (Further discussion will be made later of such fertility levels.)

Seasonal Fluctuations:

Superimposed over the fluctuations that occur within short durations are those which occur over longer periods of time, or the seasonal changes. In discussing fluctuations of nitrate nitrogen, Russell (32) brings out the point that nitrogen-producing agencies are active in the spring and work throughout summer and autumn while the nitrogen-removal agencies are active in summer and winter; hence, nitrates in an arable cropped soil are highest in the spring, drop in summer, often rise in autumn and fall again in the winter. Recent studies with Indian soils by Sahasrabuddhe (33) have indicated regular fluctuations in nitrogen content from month to month, with the highest value generally during the cooler months (November-February). Eggleton (14) found seasonal fluctuations in the total nitrogen content of grassland soils. Studying the nitrogen cycle in grassland soils at Rothamsted, Richardson (31) noted no clear seasonal changes in available nitrogen of these soils, but of the easy mineralizable nitrogen, a maximum was found in early spring and this normally decreased in summer and increased again in winter.

Long-range fluctuations, suggesting the possibilities of seasonal changes in the available nitrogen content of the unfertilized Manoa soil, are apparent from an examination of the data shown in Fig. 3. Similar trends are also noted in the fertilized soil, Fig. 2. The nitrogen level rises in fall and winter, begins to drop in spring, remains low in early summer, then begins to rise significantly in early fall, with the higher levels persisting through winter.

Fertility Levels

The growth of many of our economic crops is dependent upon nutrients, either added to or originally present in the soil and which are in available forms or can readily become available. Such factors as varieties, climatic and environmental conditions and the presence and adequacy of other nutrient elements all tend to influence the requirement in a soil for any particular nutrient. However, in general, for sugar cane culture, where the amount of soil phosphate is shown by rapid chemical analysis to be less than 30 pounds per acre, the level is low and response to phosphate fertilization may be expected. Where analyses show quantities in excess of 100 pounds per acre, the level is high and response is not likely to occur. Intermediate values have also been established. Similarly, the levels for soil potash have also been established as determined by the rapid chemical method: less than 125 pounds as "low," and greater than 300 pounds per acre as "high."

In the interpretation of soil nitrogen data, establishment of similar soil fertility levels is approached on a different basis. In the determination of nitrogen by the rapid chemical method, the analysis indicates the amount of this nutrient *present at the moment only* and does not give any indication of the rate of further formation from the non-available fraction or of the total amount that may become available throughout the entire growth period of a crop. Hence, the interpretation of the data

from soil nitrogen analysis will not necessarily be to determine the adequacy of the soil supply to furnish the entire nitrogen needs of the crop, but rather to evaluate the amount which we can expect the soil to furnish at the moment.

While many of our sugar cane soils contain between 2,500 to 12,500 pounds of total nitrogen per acre-foot of soil, this nutrient is usually found as the factor limiting cane growth. The investigations of Kelley and Burgess have shown that while nitrification occurs in all of our soils, the formation of available nitrogen from the combined nitrogen in most of our soils is negligible. Later work by McGeorge is in agreement with these findings. Observations from pot experiments, with either Sudan grass or sugar cane growing in certain acid soils within the restricted areas of the containers, have indicated that very little nitrogen can be formed which will produce growth comparing favorably with the same soils to which nitrogen fertilizers have been added.

Due to the inability of the soil to supply an adequate amount of available nitrogen from its own total store of nitrogen, the needs of the crop are not supplied and hence the usual response to nitrogen fertilization is secured. As early as 1910, from the results of field experiments, Eckart (11) called the attention of the plantation managements to the great importance of nitrogen fertilization for sugar cane in Hawaii. He stated that all the different types of soil, even those of high total nitrogen content, would give increased returns from fertilizers containing a relatively large amount of readily active nitrogen, irrespective of conditions of large or small rainfall. The agreement is general today that a definite response to nitrogen fertilization for sugar cane is almost always secured, and the major problem becomes one of determining the optimum amount to be used. In general, yield increases from applications up to 150 pounds of nitrogen per acre have been considerable, while increases for applications in excess of 250 pounds have been small.

When the nitrogen found in the soil sample by rapid chemical analysis is reliably evaluated, the corrected amount may be given due consideration when determining how much nitrogen fertilizer to apply at the time. Such consideration was demonstrated in a recent test reported by Denison (10). At the start of the second ratoon crop of H 109 cane growing in a field at Kahuku Plantation Company, Denison found the soil to contain 188 pounds of available nitrogen by the rapid chemical method of analysis (without further evaluation as outlined later in the discussion). Because of this large indicated amount of available nitrogen, fertilization was deferred for 8 months at which time the soil analysis showed very little available nitrogen left and the cane plant began to show nitrogen deficiency symptoms. Fertilization was then made at the rate of 60 pounds of nitrogen per acre, an amount considerably lower than previously applied in this area, and this amount was all that the crop received from its nitrogen fertilizer. At the age of 15 months, when this crop was harvested, the yield was equal to or better than either of the two previous crops, despite the greatly lowered nitrogen fertilization. It may be inferred that the soil had significantly contributed a large share of its available nitrogen to this cane crop. The results of this demonstration were substantiated by an "amounts-of-nitrogen" test in the same locality in which amounts of nitrogen over 100 pounds per acre (which was the minimum used in this field test) failed to produce any gains in sugar.

The above citation must not be viewed as a claim that the cane plant can make satisfactory growth with deferred nitrogen fertilization only in a soil which is high in available nitrogen. It has been known that in several instances, good growth has proceeded even in soils that were low in available nitrogen at the start and where nitrogen fertilization was deferred for several months. It may be that in such instances, the formation of the available forms through ammonification and nitrification of the soil's own supply of total nitrogen had continued at a rate that was sufficient to supply the early requirement of the crop for this nutrient.

In many fields which are in continuous cultivation, the analytical data will show equilibrium values which indicate the lowest level which may be reached by available nitrogen in the soil. At this level the nitrogen which is made available from the total supply is balanced by the amounts absorbed by plants and removed by biological agencies or by leaching. The analyses of many soils which are sampled immediately after harvest have indicated a content of from a trace to about 25 pounds per acre, except that in certain of our wetter areas, 50 to 100 or more pounds per acre may be found.

The relation of nitrogen to plant growth, as determined by the Mitscherlich procedure and by a method of chemical soil analysis has been investigated by Nemec and Koppova (26). They developed a chemical method which appears to be comparable to the Experiment Station rapid method. Their method determines the nitrates obtained by water extraction of the soil and ammoniacal nitrogen by extraction with a 0.5 normal solution of sodium chloride. Nemec and Koppova working with European soils (Praha-Dejvice) found that the momentary combined nitrate and ammoniacal nitrogen content of a number of soils agreed well with the results obtained by the Mitscherlich pot tests. Their studies indicated that .0075 per cent of available nitrogen in the soil was the lower limit to which the combined nitrate and ammonia nitrogen content should sink for satisfactory growth.

A study was made of the results of 16 of our pot experiments picked at random from a series of Mitscherlich tests of soils, with Sudan grass as the indicator crop grown during one month. The relation of available nitrogen, determined by both the biological and chemical methods of analysis, to the yield of Sudan grass was investigated. Data from this study appear in Fig. 5, the soils being arranged from left to right in an ascending order of the yields which they produced without nitrogen fertilizer. In general, it appears that yields are related proportionally to the available nitrogen supply of the soil as determined by the two methods of analysis. However, exceptions are noted for several pots which showed low availability upon chemical analysis but produced larger crop yields. The same explanation of the rate of nitrogen formation as cited for the growth of sugar cane in the field may hold true for these exceptional pots. Thus the results of this study appear to indicate that where nitrogen availability is high at the start as indicated by R.C.M. soil analysis, the yields will be larger (providing that nitrogen alone is the limiting factor). The available nitrogen supply (by R.C.M.) of the soils studied ranged from 20 to 200 pounds per acre and the soils represent cane areas from the four islands, Oahu, Kauai, Maui, and Hawaii. Total nitrogen data of these soils are also included in Fig. 5.

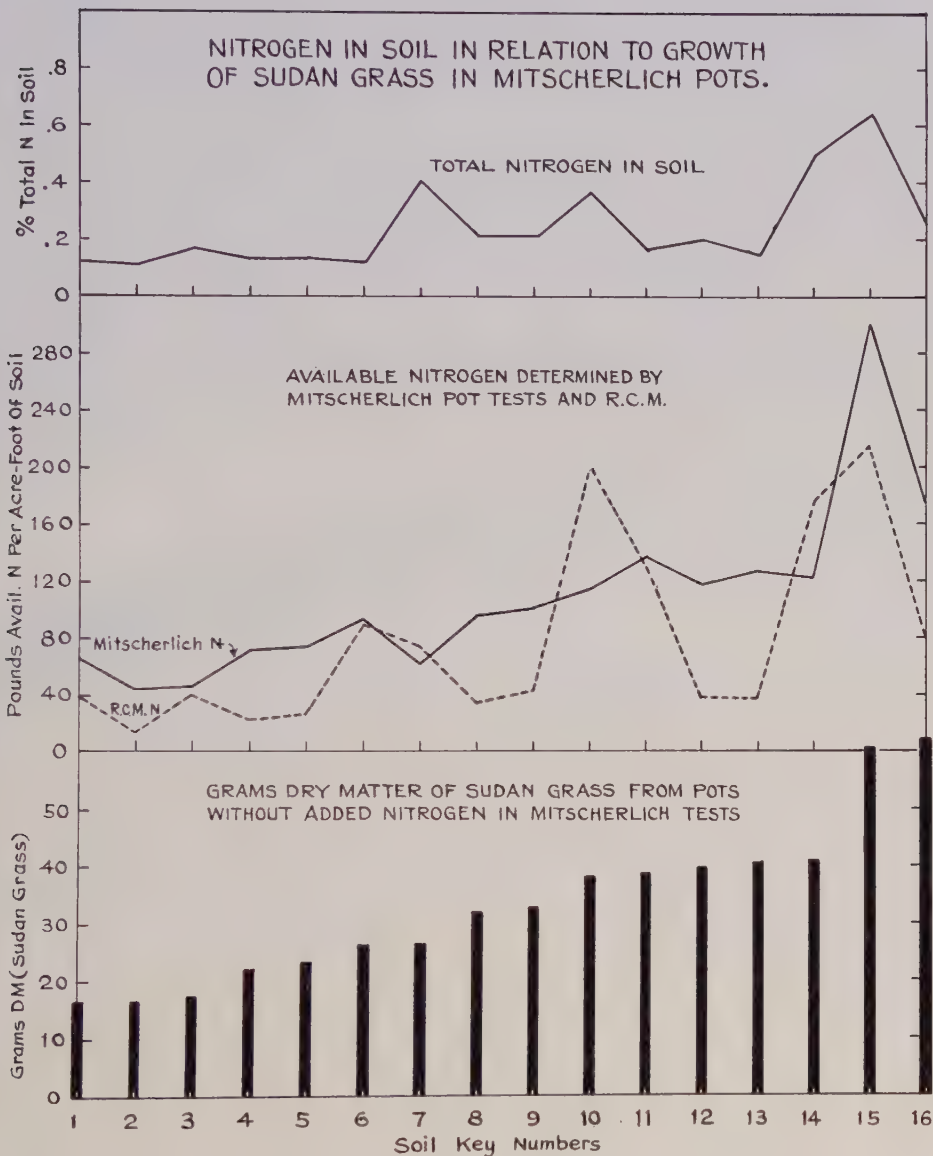

Fig. 5

It is suggested that in evaluating the R.C.M. soil nitrogen data, the levels of fertility be set as low, doubtful, medium, and high according to the following tabulation:

FERTILITY LEVELS FOR R.C.M. NITROGEN

Group	Per Cent	Pounds N per Acre-Foot of Soil
Low	—.0010	—25
Doubtful	.0010–.0020	25–50
Medium	.0020–.0040	50–100
High	+.0040	+100

When the results are within the *low* group, little significance may be attached to the amount of nitrogen present for immediate plant growth, for the reason that the values in this group may fluctuate from 0 to 25 pounds per acre. When the analytical result falls in the *doubtful* group, it may be considered as the "low" for most soils but for some soils it may have a real value. Some quantitative significance may be attached to the nitrogen in soils of the *medium* group. However, it is when the soils are in the *high* group that the nitrogen thus indicated is considered to be an immediate consequence in plant growth. "High" in this case is not to be interpreted as an indication that the soil is able to supply all the nitrogen for the entire crop requirement; it is only a qualification of the amount present at the moment. The ability of the soil to furnish all the nitrogen required is more likely to be dependent upon the rate of formation of this available form and may be independent of the amount found at the moment, which is only a measure of the accumulation at the moment of analysis.

A study of the relationship between cane yields in pot growth and soil nitrogen is presented in Table I.

TABLE I

Relation of available nitrogen in soil (original and added) to growth of sugar cane in pots.

Soil No.	Original N lbs.	Grams Dry Matter* Produced from Added Nitrogen of None	100 lbs.	200 lbs.
1	24	54	106	128
2	49	56	109	118
3	88	71	116	121
4	109	67	101	131
5	210	90	131	146
6	300	130	161	162

* Stems, leaves, and roots.

Mixtures of two Makiki soils were made so that the resultant combinations contained different amounts of available nitrogen, from 24 to 300 pounds per acre-foot of soil as indicated by rapid chemical analyses. Three sets of pots containing these soils were obtained, one of these was left without nitrogen fertilizer additions while to the other two sets additional nitrogen, at the rate of 100 and 200 pounds per acre respectively, was added. Phosphate and potash were supplied in ample amounts and the pots were planted to H 109 cane shoots. After growing until all pots showed definite signs of nitrogen deficiency the pots were harvested and the yields of dry matter were obtained. The data appear to indicate that yields were alike for each respective series where the soils showed initial analyses below approximately 100 pounds nitrogen per acre, but when they had more than 100 pounds, the yields were increased correspondingly. Hence the results support the 100-pound level from our R.C.M. analysis as being a critical amount significant for growth requirements.

Thus, two levels can be established—low and high—to which a significance of inadequacy or adequacy of the amount determined by R.C.M. analysis may be attached. These levels form the qualitative test of the soil's available nitrogen supply. Where a quantitative estimate is desired, so that an allowance can be made in the fertilizer schedule for the amount determined by the analysis, a factor of safety

should be applied which will take into consideration the sampling fluctuations which occur. Such a factor has been estimated from data at hand and is arbitrarily set at 50 per cent or one-half of the amount determined when such amount is greater than 100 pounds per acre-foot. This factor may also be applied to the results in the medium group if several consecutive samples show results that fall within the percentage limits for this group.

Thus in evaluating the R.C.M. soil nitrogen data, we would proceed as follows: (1) classify the soil qualitatively as low, (doubtful, medium,) or high; and (2) if the analytical results place ~~the soil~~ in the "low" group, disregard them quantitatively, but if the "high" group is indicated, then multiply the indicated pounds per acre-foot by one-half to determine the corrected amount for which a nitrogen allowance may be made in the subsequent nitrogen fertilization.

The practical application of this procedure may be illustrated by the use of data cited in the Kahuku test. The initial analysis showing the presence of 188 pounds of nitrogen per acre-foot of soil, places this soil in the "high" group for nitrogen. If this nitrogen is to be given consideration in the fertilizer schedule, then one-half of 188 or 94 pounds may be deducted from the regular amount to be applied. As stated in the earlier part of this discussion, the usual nitrogen application for sugar cane crops is between 150 to 250 pounds. The minimum requirement of nitrogen to produce an economic crop of cane remains to be determined. This minimum will no doubt depend upon the variety, soil, climatic and environmental conditions, and the adequacy of other nutrients. Assuming that the minimum requirement for the crop under consideration is 200 pounds per acre, then 200 minus 94 or 106 pounds of nitrogen would need to be added to make up the balance required. The actual addition of 60 pounds of nitrogen per acre for the Kahuku crop was found to produce a satisfactory yield, and the amounts-of-nitrogen test for this area showed that quantities over 100 pounds failed to produce further gains in sugar.

Plant Growth Studies

In the preceding discussion the available nitrogen status in a soil free from plant growth has been considered. The next concern is with the available nitrogen level in the soil as influenced by plant growth and more especially the relationships between nitrogen fertilization and plant growth, particularly the rate of absorption, the recovery of the nutrient in the harvested material, and the rate of plant growth.

The experiments were conducted with both Sudan grass and sugar cane grown in Mitscherlich pots, in an acid soil from Manoa. The results obtained from both crops were comparable and lead to the same general conclusions. Hence the data and discussion presented here will deal mainly with the sugar cane series.

Experimental:

Data concerning the available nitrogen status of a soil under plant growth, and the absorption of nitrogen by sugar cane were obtained from several experiments in which H 109 cane shoots were planted in Mitscherlich pots. The details of one of these experiments will be described below while the others will be presented under the respective sub-phases that follow. Phosphate and potash were added to a Manoa

(Field 21) surface soil at the rate of 9.4 grams P_2O_5 and 4.3 grams K_2O per 4½ kilograms of air-dry soil. Nitrogen at the rate of 1.5 grams N from ammonium nitrate solution was added to each pot. Soil and fertilizer ingredients were thoroughly mixed before potting. Two pregerminated shoots from one-eye cuttings of seed pieces were planted in each pot. These shoots were germinated in sand boxes and grew for one month before transplanting. Irrigation was applied regularly in amounts ample for plant growth. Check pots fertilized but without growing plants were also started, the data of which were previously reported in Fig. 4 of this report.

At periodic intervals, soil samples were obtained for KCM analysis of available nitrogen, and plants were harvested for yields of dry matter and total nitrogen determinations. The sampling followed a procedure of taking one or two pots (at random); harvesting the cane plants, separating the roots from the soil by a careful process of picking and screening; and thereafter thoroughly mixing the soil. A portion of this mixed soil was then removed for the immediate determination of the available nitrogen. The plant material was oven-dried, weighed, and prepared for total nitrogen determination. The experiment was continued for 7 months. Data from this experiment appear graphically in Figs. 6, 7, 12, and 14.

Available Nitrogen Levels in Soil Supporting Cane Growth:

Due to the additional factor of absorption by the crop, the nitrogen status of a soil in which plants are growing is often different from that existing in an uncropped soil. In the presence of active plant growth, the forces concerned with nitrogen removal may dominate those concerned with its accumulation and hence the nitrogen level is generally low. It has been shown by Albrecht (1) from a study of Missouri soils under different crops and treatments that the crop is a significant factor in removing nitrates from the soil and that the exhaustion of this nutrient is closely similar for the same soil whether the crop is grass, oats, or wheat. Similarly it has been found by Richardson (31) and Eggleton (12) that the amount of nitrate nitrogen in grassland soils is usually low under good growing conditions.

Richardson studying grassland soils at Rothamsted pointed out that neither ammonia nor nitrate was normally accumulated to any extent in these soils and in general the ammonia level was above that of the nitrate. He found that ammonia added to these soils disappeared in the short period of a few weeks in winter or a few days in late spring. Nitrates were found only in small amounts. Added nitrates disappeared as rapidly as ammonia. It was further indicated that ammonia nitrogen was as readily removed from an acid soil as was nitrate when herbage was present but that it remained if the herbage was removed.

The retention of nitrates by Ewa soils under field conditions in which H 109 cane was growing was studied by Stewart and Hansson (34). Nitrogen was added to the soil in two applications of 100 pounds each to cane about age 5 months old at the start of the experiment. Analytical data indicated that the nitrate content of the soil had been reduced to the level prevailing before fertilization within 8 to 12 weeks after the first fertilization and a still shorter period after the second fertilization. Since soil nitrogen [illegible] it was concluded by these investigators that the rapid disappearance of nitrates was caused by the extraction of this nutrient through the growth of the cane crop.

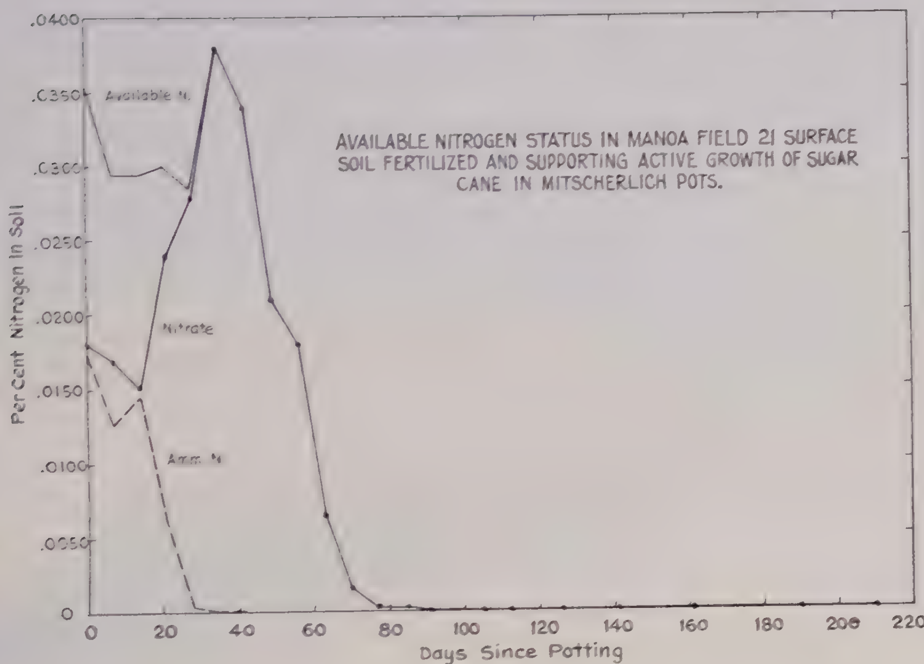

Fig. 6

The available nitrogen data for the soil supporting active growth of sugar cane in pots of the experiment conducted for this study are presented graphically in Fig. 6. The original air-dry soil with phosphate and potash added showed an analysis of .0010 per cent available nitrogen. The addition of the nitrogen fertilizer brought this value to .0355 per cent. It will be noted that starting with the level of .0355 per cent, the percentage of nitrogen decreased during the growth of the cane plants until, at approximately 90 days or about 13 weeks following transplanting of the shoots, only a trace or practically no nitrogen remained in the soil as determined by R.C.M. analysis. The available nitrogen status of the same soil receiving identical fertilization but free from vegetation may be obtained in Fig. 4.

The nitrogen level continued to be low following soil depletion and during the subsequent period of active growth. This result is consistent with the findings of others cited above for grassland and other soils under crops. It is apparent that if the root mass is confined within a restricted area as found under the pot conditions, depletion of nitrogen may be carried to the point where practically no accumulation can occur and hence the extremely low level is constant.

Albrecht (1) in discussing the determination of available nitrogen in the soil under an equilibrium status points out that such a measure is not an indication of the quantity of nitrogen removed or produced; rather, it is the lowest level which represents a balance of the forces of accumulation against removal by cropping, microorganisms or other agencies, and leaching. He found the equilibrium values for grass and wheat to be between 6 to 12 pounds. Stewart and Hansson (34) reported in one instance 6 to 15 pounds per acre for Ewa soils under H 109 cane, and in the present pot study the data indicate that the level may be as low as nil. In an experi-

ment (6) recently completed to study the status of available nutrients during the active cropping of sugar cane in a plantation field it was found that the equilibrium level of nitrogen in the soil at the start of the crop averaged 25 pounds. With each fertilization the level was significantly raised and rapidly lowered following a short interval. The equilibrium level of nitrogen in the soil when the cane was mature was not much higher than that at the start.

Rates of Absorption:

As stated previously the nature of the pot experiment was such that loss by leaching need not be considered as a factor in this study. Excepting its removal by immobilization in microorganisms or loss through gaseous evolution, the nitrogen indicated by R.C.M. analysis as removed from the soil was assumed to be absorbed

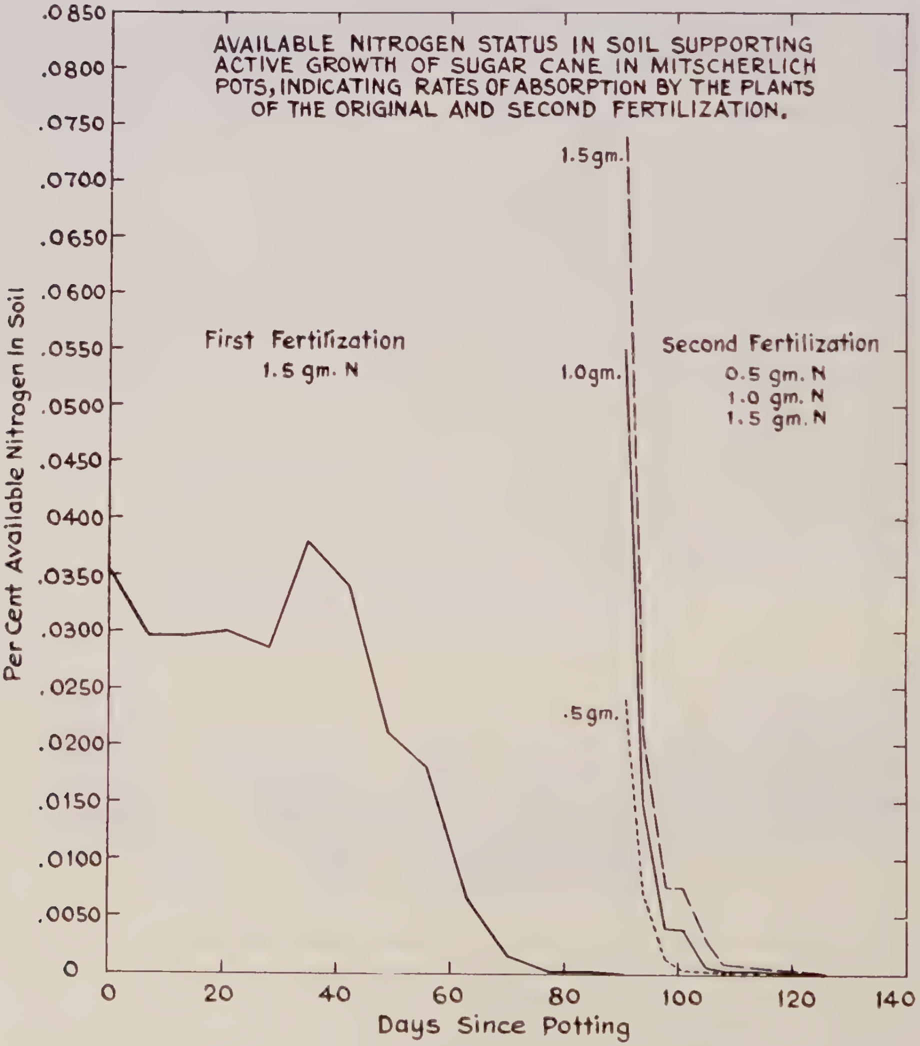

Fig. 7

by the growing plants. Hence the rate with which available nitrogen disappears from the soil may be employed in this study to indicate the rate with which the cane plant can absorb its nitrogen. It has been shown by Richardson that grass can absorb nitrogen at various rates depending on the time of application and the age of the crop. Stewart and Hansson found that under field conditions, H 109 cane was able to absorb the second application of nitrogen much quicker than the first.

The rates with which the cane growing in pots can absorb nitrogen may be obtained from a study of Figs. 6 and 7. It will be noted that nitrogen absorption is very slow at the start following transplanting of the month-old shoots. After the first 4 weeks, however, the soil showed a rapid disappearance of its available nitrogen, indicating an absorption by the growing cane at an accelerated rate. From a consideration of the comparative root system of the shoots at planting with that which had developed at about 4 or 6 weeks following transplanting, it is reasonable to conclude that with the enlarged root area an enhanced rate of absorption should occur. This should account for the increased rate of depletion that is noted in the soil following this period.

Effect of Age Upon the Rate of Absorption:

The original pot experiment was modified for a study of the rate of absorption during the stage of growth when the root system was enlarged and fully developed. Following the depletion of the first application of 1.5 grams nitrogen, pots from this experiment were divided into three series, and refertilized at the rate of ½, 1, and 1½ grams of nitrogen from ammonium nitrate solution applied to the surface. It was found by soil analysis that this second and later fertilization was removed from the soil within a period of about 6 weeks in contrast to its depletion from the soil with younger cane at about 13 weeks. Soil data comparing the disappearance of nitrogen in the soil following the original fertilization and the subsequent applications are presented in Fig. 7.

Additional data are presented in Fig. 8 which illustrates the quicker rate of absorption of nitrogen from somewhat later applications than those given during the first few weeks following planting. The results are from an experiment wherein a total of 1.5 grams of nitrogen was applied in three applications of ½ gram each in the following manner. The first increment was applied at the start to all series; for the subsequent increments: to Series 1, as soon as the soil analysis showed depletion of nitrogen; to Series 2, one week after the soil was depleted of nitrogen; and to Series 3, when the plants showed definite signs of yellowing. This procedure was followed until the total of 1.5 grams of nitrogen had been added. The data show that the nitrogen is more rapidly removed from the soil in the subsequent applications than in the initial application. A chart comparing the removal in Series 1 with the removal when the nitrogen was added as a single application is presented in Fig. 9.

Effect of Time of Application on the Rate of Absorption with Respect to Age:

In the preceding paragraphs the rate of absorption as affected by the age of the plant was discussed. The data were obtained under conditions of plant growth where nitrogen was applied to the soil at the start of the experiment. Data relevant

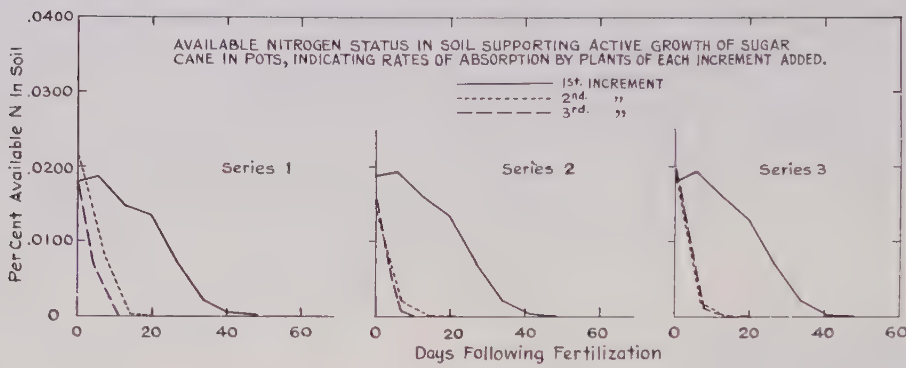

Fig. 8

to the rate of absorption as affected by the time of application are presented in the following discussion. Two pregerminated shoots of H 109 cane (age one month) were transplanted to each Mitscherlich pot which had been fertilized with sufficient phosphate and potash. Nitrogen in applications of 1.5 grams per pot was applied at variable intervals following planting. Soil samples were taken at weekly intervals for the determination of available nitrogen. The results of this experiment appear in Table II and Fig. 10.

TABLE II

Days required to effect complete removal of added nitrogen from soil growing H 109 cane (2 plants) in Mitscherlich pots. Application of 1.5 grams nitrogen, equivalent to 426 pounds N per acre.

Treatment	Days required for removal of nitrogen applied
NPK at planting	84
PK at planting, N at 21 days	63
PK at planting, N at 42 days	71
PK at planting, N at 56 days	64
PK at planting, N at 84 days	63

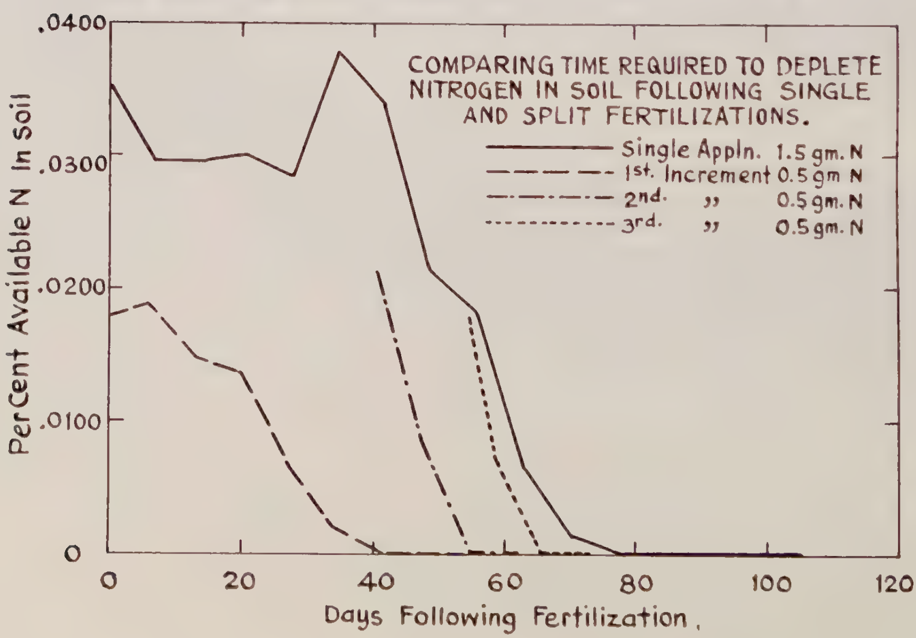

Fig. 9

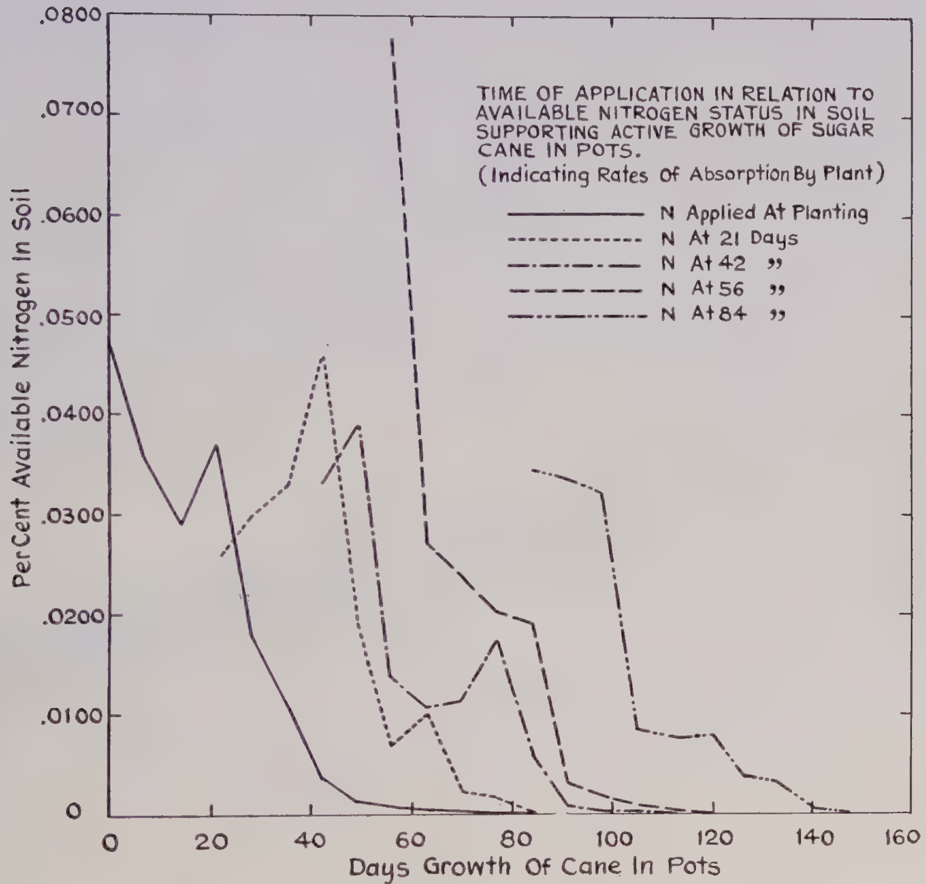
TIME OF APPLICATION IN RELATION TO AVAILABLE NITROGEN STATUS IN SOIL SUPPORTING ACTIVE GROWTH OF SUGAR CANE IN POTS.
(Indicating Rates Of Absorption By Plant)
N Applied At Planting
N At 21 Days
N At 42 "
N At 56 "
N At 84 "
Per Cent Available Nitrogen In Soil
Days Growth Of Cane In Pots

Fig. 10

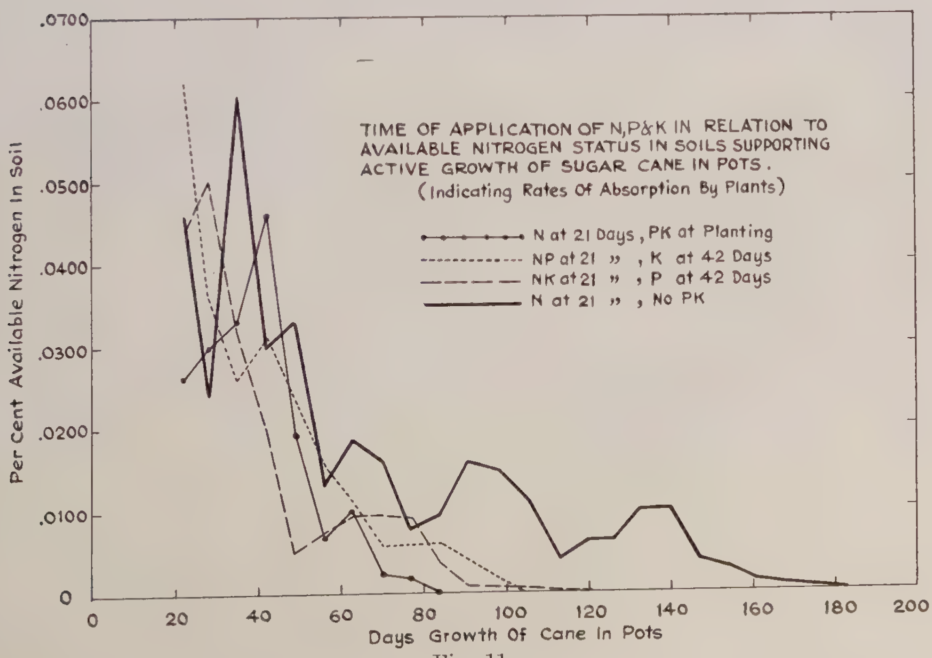
TIME OF APPLICATION OF N,P&K IN RELATION TO AVAILABLE NITROGEN STATUS IN SOILS SUPPORTING ACTIVE GROWTH OF SUGAR CANE IN POTS.
(Indicating Rates Of Absorption By Plants)
N at 21 Days, PK at Planting
NP at 21 " , K at 42 Days
NK at 21 " , P at 42 Days
N at 21 " , No PK
Per Cent Available Nitrogen In Soil
Days Growth Of Cane In Pots

Fig. 11

Data indicate that a shorter period is required for nitrogen removal after the plants have grown for a while, than when nitrogen was applied at the start. This is to be expected from the results of the preceding study. During the early period when only slight root development had taken place, very little absorption is to be expected. Evans (15) in a recent study on the effect of the root system on the absorption of nutrients by White Tanna cane reports that absorption is affected by the age and size of the root system, and also by the environmental conditions surrounding the roots.

Effect of Other Nutrients on the Rate of Nitrogen Absorption:

The effect of applications of N, P, and K at different intervals of time on the rate of nitrogen absorption by a growing crop was investigated in a pot experiment where these factors were considered. The Manoa soil used in this experiment contained 600 pounds phosphate as P_2O_5 per acre by rapid chemical analysis, an amount usually considered to be ample for crop growth under field conditions. Available potash was low in this soil. The plan of treatments and the results of this experiment are presented in Table III and Fig. 11.

TABLE III

Days required to effect complete removal of added nitrogen in soil supporting growth of H 109 cane in Mitscherlich pots. Applications of 1.5 grams N, 9.0 grams P_2O_5 and 1.5 grams K_2O at different intervals.

Treatment	Days required for removal after fertilization	Grams dry matter produced: Stalks and Tops	Trash	Total Aerial
At planting, N, P, K	84	156	75	231
At 21 days, N; at planting, PK	63	173	80	253
At 21 days, NK; at 42 days, P	99	176	69	245
At 21 days, NK; at 56 days, P	99	186	49	235
At 21 days, NP; at 42 days, K	84	185	64	249
At 21 days, NP; at 56 days, K	84	198	72	270
At 21 days, N; at 42 days, PK	99	161	67	228
At 21 days, N; at 56 days, PK	99	158	66	224
At 21 days, N only; no PK	161	50	33	83

Data appear to indicate that in addition to the time of nitrogen application, the time of addition of phosphate and potash exerted an influence over the rate of nitrogen uptake by the cane plant as indicated by soil analysis. In Fig. 11 the rates of nitrogen removal under 4 treatments of this test are compared. Nitrogen was applied to these 4 treatments at 21 days, while phosphate and potash were added either at the start, at 21 days or at 42 days. It will be observed in Fig. 11 that while the soil nitrogen was reduced to a low level in the 4 treatments at the end of the seventh week following nitrogen fertilization, a reduction to a zero level would be affected by the time of applying the phosphate and potash. While available phosphate was high in the soil, it appears that this nutrient added from fertilizer exerted the greater influence in the removal of N from the soil. Omission of phosphate and potash from fertilization resulted in the longest interval required for final depletion of nitrogen in the soil.

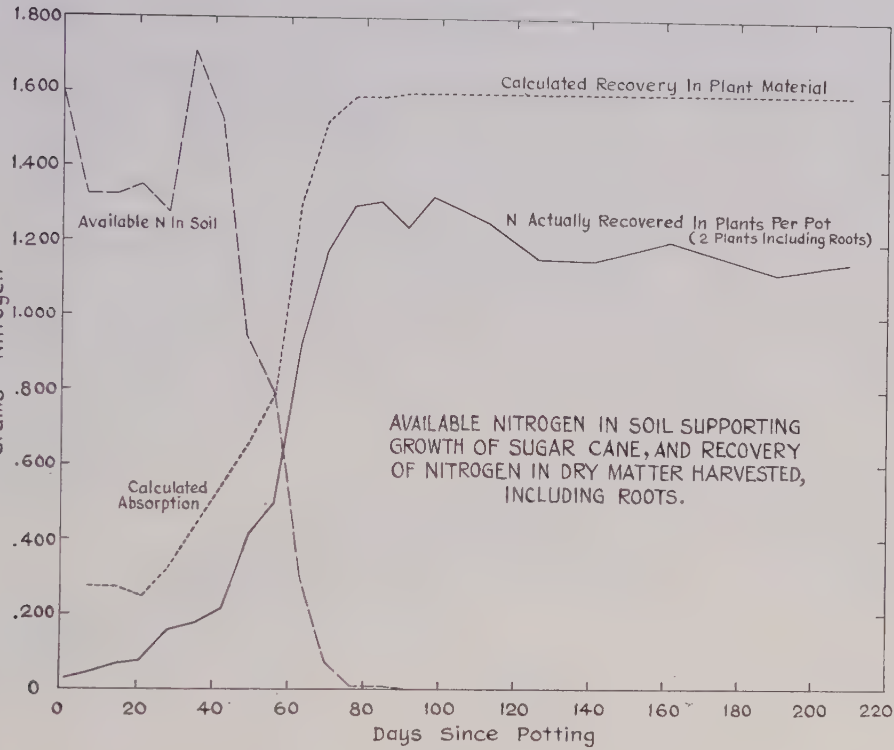
AVAILABLE NITROGEN IN SOIL SUPPORTING GROWTH OF SUGAR CANE, AND RECOVERY OF NITROGEN IN DRY MATTER HARVESTED, INCLUDING ROOTS.
Calculated Recovery In Plant Material
Available N In Soil
N Actually Recovered In Plants Per Pot (2 Plants Including Roots)
Calculated Absorption
Grams Nitrogen
Days Since Potting

Fig. 12

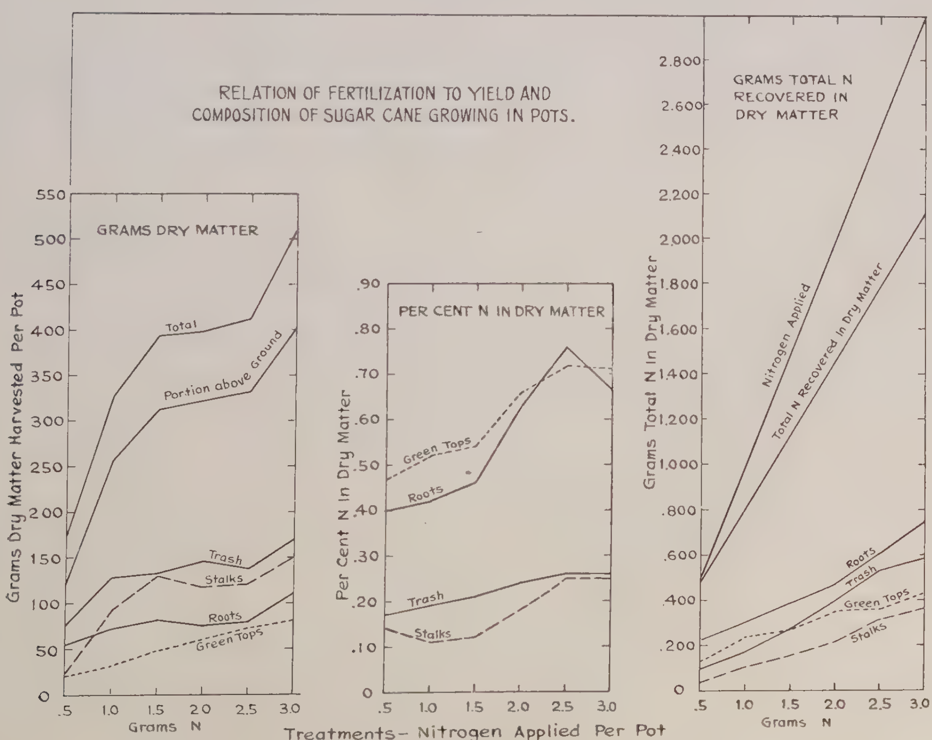
RELATION OF FERTILIZATION TO YIELD AND COMPOSITION OF SUGAR CANE GROWING IN POTS.
GRAMS DRY MATTER
Grams Dry Matter Harvested Per Pot
Total
Portion above Ground
Trash
Stalks
Roots
Green Tops
Grams N
PER CENT N IN DRY MATTER
Per Cent N In Dry Matter
Green Tops
Roots
Trash
Stalks
GRAMS TOTAL N RECOVERED IN DRY MATTER
Grams Total N In Dry Matter
Nitrogen Applied
Total N Recovered In Dry Matter
Roots
Trash
Green Tops
Stalks
Grams N
Treatments- Nitrogen Applied Per Pot

Fig. 13

Recovery of Nitrogen in Plant Material:

In the pot experiment with sugar cane previously described in this report and for which soil data were presented, plant material was harvested concurrently with soil sampling. Hence an analysis of the dry matter produced will show whether the nitrogen indicated by soil analysis to have been removed was actually absorbed by the plant.

The available nitrogen status of the soil during plant growth and the analytical data for total nitrogen in plant material harvested periodically during concurrent instances appear graphically in Fig. 12. The results appear to indicate that as the available nitrogen level in the soil declined the nitrogen recovered in the plant material increased. When the soil reached its initial lowest point of depletion, the nitrogen recovered in the cane sample was at its maximum. The rate of absorption as indicated by soil analysis, paralleled that indicated for the accumulation in the plant tissues. Nitrogen appears to be absorbed at a slow rate from the beginning to the fourth week. Thereafter a rapid accumulation is noted, ending on the thirteenth week, but after this time the amount of nitrogen contained in the plants (including roots) did not increase. A decrease is noted between the fifteenth and eighteenth week, but thereafter the amount recovered appears practically constant.

The Effect of Nitrogen Fertilization on the Yield and Composition of the Cane Plant:

The preceding discussion has been concerned with the available nitrogen status of a soil under conditions of plant growth, and has dealt with the removal of this nutrient from the soil and its absorption into the tissues of the sugar cane plant. In this next discussion, the relationship of nitrogen fertilization to the yield and to the composition of this yield is considered. Pot experiments with H 109 cane were conducted using Manoa soil fertilized with phosphate and potash. Nitrogen was applied in the following amounts: ½, 1, 1½, 2, 2½, and 3 grams per pot for two pregerminated cane shoots. The plants were grown for 210 days and then harvested. The yields of dry matter including roots were obtained and determinations of total nitrogen in the plant material were made. The results of this study appear in Fig. 13, the data representing the average of two pots of each treatment.

Yield—The total yield is found to increase with the amount of nitrogen applied, as is to be expected. The harvested material has been segregated into trash (dead leaves), millable stalks, green tops, and roots.

Percentage of nitrogen in dry matter—Not only is the differential fertilization reflected in the growth of the sugar cane but it is also found to affect the percentage composition of nitrogen in the dry matter of the plants. With increases in nitrogen fertilization, the concentration of this nutrient is increased in all sections of the cane plant (Fig. 13), the percentage composition being greatest in the roots and green tops.

Nitrogen recovered in dry matter Loss of nitrogen—The analytical results showing the total nitrogen in the plants harvested from the differentially fertilized pots also appear in Fig. 13. The amounts of nitrogen contained in the different parts of the plant are shown, together with the total amount recovered in all sections

including the roots. It will be seen that a considerable portion of the nitrogen was found in the roots and trash. About 20 per cent of the amount added or 30 per cent of the total nitrogen recovered was found in the green tops.

The relationship which the amount of nitrogen recovered in the dry matter bears to the quantity applied offers an interesting study. Data in Fig. 13 indicate that the amount recovered is not equal to that which was applied. It appears that approximately only 70 per cent of the nitrogen applied is recovered in the plant tissues. The reason for this apparent loss is not definite. The experiments which have been completed thus far have been designed to determine whether there is any loss of nitrogen either from the soil or plants, rather than to seek an explanation for this occurrence.

In a previous preliminary experiment with Sudan grass, data were secured which appear to indicate that during the early period of growth and coincident with the removal of nitrogen from the soil, there was a loss of the available form of this nutrient from the soil. A considerable loss of nitrogen from the plant was found to occur while the Sudan grass plants were flowering and forming seed. The amount of nitrogen recovered at maturity was approximately only two-thirds of that recovered at the period when the nitrogen content was the highest; nitrogen at the forty-fifth day of growth averaged about 950 milligrams, while that found at harvest at 85 days was about 625 milligrams.

Referring again to Fig. 12 it will be seen that even at the start of the experiment there is an apparent discrepancy between the amount recovered in the harvested cane and that calculated to have been removed from the soil. The theoretical absorption was calculated from soil data by subtracting the nitrogen determined at each period from the original analysis. The differences represent the amount theoretically absorbed. The deficient amount appears to be constant up to the period of maximum uptake which came at around 90 days. Whether this initial deficiency represents nitrogen immobilized in the organic fraction of the soil or nitrogen lost from the soil as elemental nitrogen through reduction processes remains problematical. The limitation of the scope of the experiment and the data obtained do not offer a conclusion or solution. Following the period of maximum concentration in the cane plant as evidenced in Fig. 12, it will be noted that there is a drop from the ninety-eighth to the one hundred and twentieth day and that thereafter the nitrogen remains practically constant. The maximum concentration averages about 1300 milligrams while that at the later stages of growth from the one hundred and twentieth day on, averages approximately 1150 milligrams or a difference between maximum and minimum of 150 milligrams per pot of two plants, which the data suggest as being lost from the plant. In the case of Sudan grass, the loss was much greater, due perhaps to the growth processes concerned with its seed-formation stage. In the experiment with cane, the tasseling or flowering stage of growth was not reached. It has been shown by other investigators that during the tasseling stage of the sugar cane there is movement and relocation of the nutrients in the plant.

The possibility of considerable loss of nitrogen during the processes of nitrate reduction as a feature of nitrogen metabolism of plants has been advanced by Pearsall and Billimoria (*27*). The loss of nitrogen in its elemental form as free nitrogen from plant tissues as a result of chemical interaction has been studied by these Eng-

lish investigators. The chemical theory advanced is similar to that obtaining in the Van Slyke method of determining amino nitrogen whereby nitrous acid if present in the acid plant tissues may react with monoamino nitrogen to give elemental nitrogen.

The rate of absorption did not appear to affect the recovery of the nitrogen found in the plants during the period of maximum plant concentration. Thus, whether the nitrogen was applied at the start with its consequent longer period of absorption, or applied in split portions with its quicker and shorter period of uptake, the amounts of nitrogen found in the plants were practically alike in all treatments. This is apparent in studying the results of the experiments in which nitrogen was supplied as single or split applications. The amounts of nitrogen theoretically recoverable for each experiment include the amount originally present in the soil, the amount found in the seed pieces, and the amount added as fertilizer. The data are for each pot of two plants. The results of these experiments appear in the table below:

TABLE IV

Grams nitrogen recovered in harvested material per pot of two plants.

Treatment: No. of Appli-cations	Treatment: Gms. N per Appln.	Treatment: Total Gms. N applied	Theoretical recoverable	Total Det'd in dry matter	Difference between theoretical and found	Undetermined for each ½ gram increment
1	.5	.5	.610	.451±.005	.159	.159
2	.5	1.0	1.110	.851±.005	.259	.100
3	.5	1.5	1.610	1.275±.006	.335	.076
1	1.5	1.5	1.576	1.288	.288	....

It will be noted from the above table that while the loss for each increment is greater for the one made earlier, the total quantity unrecoverable at the period of maximum content was nearly the same for both the split and single applications of 1.5 grams of nitrogen.

While the results of these studies have suggested the possibility of loss of nitrogen during the early period of plant growth coincident with absorption, and during the later stages of growth after the concentration of this nutrient has reached a maximum, the real reasons for this phenomenon are still vague and indefinite. Possible explanations which have been suggested are: (1) nitrogen added to the soil may have become immobilized in the organic fraction of the soil as indicated in studies discussed in the first part of this report, and all of the nitrogen thus fixed may or may not become available later upon nitrification; (2) nitrogen may become dissipated to the atmosphere either as gaseous oxides or in the elemental form through bacterial or chemical reactions; and (3) nitrate reduction in plant tissues may set nitrogen free as discussed by Pearsall and Billimoria (27). As suggested by these English investigators, this phase of nitrogen metabolism in plants deserves further consideration.

This apparent deficiency between the amount of nitrogen applied and the amount recovered has practical significance when plant analysis is to be used to determine the needs of a crop. Thus, if upon analysis at maturity, the crop is found to contain a certain quantity of nitrogen, this may or may not represent the amount needed at an earlier period in its growth. Due to the possibility of a loss of nitrogen from

the tissues, the requirement for this nutrient may have been higher than that indicated by analysis at maturity.

Growth of Sugar Cane and Nitrogen Absorption:

The point has often been raised as to whether a continuous absorption of nitrogen is necessary for the best growth of the cane plant or whether large amounts taken up at some one period can carry the crop to maturity or for a sustained period of growth. The solution of this has a bearing on the practical aspects of nitrogen fertilization as it concerns the problem of single or split applications. Many investigators have indicated that plants may be able to store up nutrients above their momentary needs in their tissues and draw upon these stores for growth. The results of this present study have indicated that the cane plant can absorb large quantities of nitrogen at a rapid rate during its early period of growth. This nitrogen content of the plant material as a result of absorption reached a maximum within a period of 90 days. However, growth during this period yielded less than one-half of the total dry weight including roots which was obtained at 210 days. The data of nitrogen absorption and growth, as indicated by yield of dry matter, are presented in Fig. 14. From this graph it will be seen that growth did not parallel absorption, that is, growth did not end with the cessation of absorption. Growth between the eighth and the twenty-third week proceeded at a constant rate of increase, whereas nitrogen absorption had ceased and reached the maximum after the twelfth week.

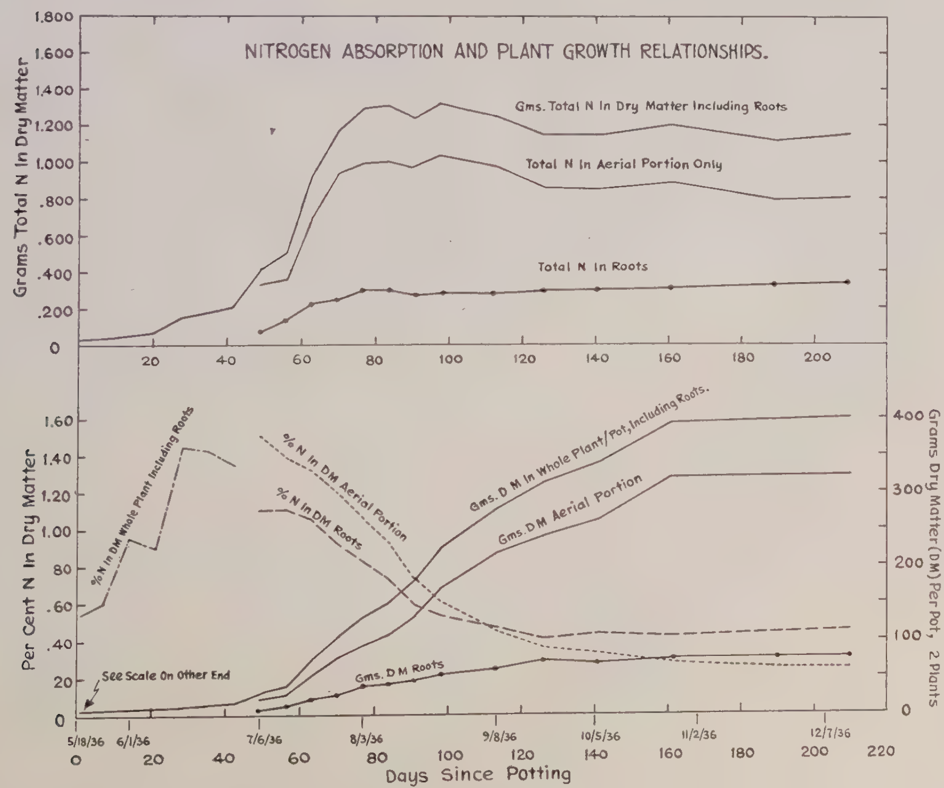

Fig. 14

It may be inferred that if a sufficient amount of nitrogen is supplied, and providing that this element is the limiting factor, the nutrient even if absorbed during the early period when only little growth is taking place, will suffice to carry the crop to maturity.

Importance of an Adequate Supply:

The requirement of an adequate supply is evident from the results obtained in another similar experiment. To one series of pots was added ½ gram of nitrogen, to another 1.0 gram, and to the third series 1.5 grams of nitrogen, all from ammonium nitrate solution. The nitrogen was added in ½-gram increments. The first increment of ½ gram was added to all pots at the same time. Each subsequent increment of nitrogen to make up the required total was added to the pot as a surface application as soon as the soil analysis showed the previous application to have been absorbed by the growing cane. Periodic harvestings were made to determine the growth throughout the period of the experiment. The results presented in Fig. 15 appear to indicate that the ½-gram application was not sufficient to make sustained growth. The cane was able to make additional growth for only 56 days after the ½ gram of nitrogen was absorbed or approximately 104 days after potting. The second and third fertilization making total applications of 1.0 gram and 1.5 grams of nitrogen respectively, extended the growing period to 154 days, as compared with 104 days for the ½-gram treatment. The third increment increased the rate of growth over that shown by the 1.0-gram treatment.

Effect of Single and Split Applications of Nitrogen on the Yield of Sugar Cane:

In field experiments with sugar cane the results showing the relative efficiency of single versus split applications have not been conclusive. This phase will be con-

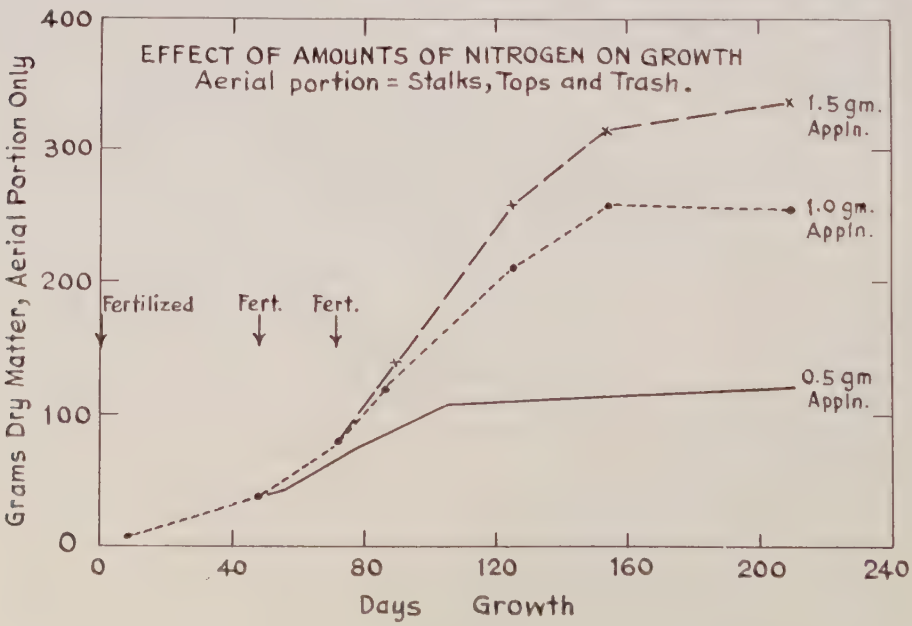

Fig. 15

sidered for cane growing in pots. The rate of absorption of nutrients by sugar cane resulting from single or split applications of 1.5 grams of nitrogen per pot of two shoots have been reported in Figs. 6 and 8. The yields of plant material for these treatments are being presented for examination. It will be recalled that the split applications were divided into three series: Series 1, nitrogen applied whenever soil analysis showed the previous application to have been removed; Series 2, nitrogen applied one week after the previous application had been removed; and Series 3, nitrogen applied only when the plants showed definite symptoms of deficiency as evidenced by the uniform yellowing of foliage. The yields of dry matter of different parts of the cane plant for the single application and for the three series are presented in Table V. The data shown in the table represent averages of five pots for each treatment:

TABLE V

Yield of dry matter as a result of single and split applications of 1.5 grams of N per pot of two H 109 cane shoots. Four and one-half kilograms of soil amply fertilized with phosphate and potash.

	Grams Dry Matter Harvested			
Treatment	Roots	Trash	Green Tops	Millable Stalks
Single application	69.7	126.3	49.6	134.2±2.6
Series 1	88.7	149.7	44.3	143.0±4.2
Series 2	78.7	143.9	50.4	132.4±4.4
Series 3	74.4	130.0	54.2	117.0±3.1

It will be seen from the above table that a significantly greater production of millable stalks is possible if the application is split and applied continuously without delay (Series 1) than if the nitrogen is split and applied only when the plants show deficiency symptoms (Series 3). A single application versus Series 1 and 2 did not show a significant difference.

A similar trend showing lowered production resulting from too long a delay in fertilization may be found from the results of the experiment concerned with the time of application with respect to age, in which the rate of nitrogen removal is shown in Fig. 10. The yield data for this experiment follow:

TABLE VI

Yield of dry matter resulting from a time-of-nitrogen-application test of H 109 cane in pots. Total growth, 94 days after potting. PK added at start, N at variable intervals.

	Grams Dry Matter Harvested				
Treatment	Stalks + tops	Trash	Roots	Aerial portion of plant	Total, incl. roots
N at start..........	156	75	59	231	290
N at 21 days.......	173	80	62	253	315
N at 42 days.......	182	75	42	257	299
N at 56 days.......	157	68	53	225	278
N at 84 days.......	159	43	44	202	246

The results of the test appear to indicate that when nitrogen was applied in the twelfth week after transplanting, the yield of dry matter was not as favorable as for the earlier applications. Fertilization at 3 to 6 weeks after the transplanting of the month-old shoots appears to be the optimum for growth. The soil in these pots was low in available nitrogen at the beginning of the crop.

General Discussion of Results With Respect to Field Problems

It is apparent that nitrogen analyses by rapid chemical methods may be used as an aid to intelligent nitrogen fertilization. Although some wide fluctuations are likely to occur in analyses of individual soil samples from the same area, such variations need not be considered too great to afford a fairly reliable interpretation, when the limitations of the analysis are fully recognized. Hence it is believed that when a "high" level of available nitrogen is found, one may conservatively figure on at least 50 per cent of the indicated amount as being immediately available for crop growth, and that an allowance may be made for this in the subsequent nitrogen fertilizer application.

An interpretation of a "low" level of available nitrogen in the soil sample in relation to growth during a long period of time is somewhat difficult. Until more evidence is available, one must be cautious in an interpretation. Cropped soils usually show this "low" level, although the crop growing on such soils may have taken up a very large supply which it apparently can store up and continue to use. Data from these studies indicate that growth continues long after nitrogen absorption ceases (when due to the depletion of the available supply in the soil) and that such growth is apparently regulated by the amount of nitrogen which was absorbed before this point was reached.

It is quite apparent that where a real nitrogen deficiency exists at the start of a crop, as indicated when the R.C.M. nitrogen analyses at this time show less than 40 or 50 pounds per acre-foot, a delay in the application of nitrogen fertilizer will result in retarded growth which will be quite evident when the delay extends for a period of more than 5 or 6 weeks. On the other hand, if a readily soluble nitrogen fertilizer is supplied too early, i.e., before the root system is well started, the rate of absorption is only about half as fast as it is when the root mass has more fully developed. Hence, under field conditions where loss of nitrogen by leaching can be expected, or where the biological activities of soil organisms are taking up their quota from this available nitrogen, one can expect that the quantity of this nutrient which is obtained by the immediate cane crop from an early application will be somewhat less than that from a late fertilization when the plants are able to absorb this nutrient more rapidly.

Both the time of applying the nitrogen (with respect to an adequate development of the root system) and the amount of nitrogen supplied have been shown to affect its rate of absorption. Similarly the time of applying both phosphate and potash shows its influence on the uptake of nitrogen, for when P_2O_5 or K_2O, singly or combined, were supplied three weeks after the nitrogen application had been made, the nitrogen uptake was considerably delayed; this was especially true when the phosphate application was late.

The fact that only a negligible amount of the applied nitrogen was found in the soil three months after an application had been made to one-month-old cane growing in pots, and also that the complete uptake of nitrogen by the cane from an application which was made when the crop was four months old was accomplished in less than 30 days, leads one to feel that even under field conditions, if the nitrogen fertilizer is applied in an active root-feeding zone, its rate of absorption therefrom will be quite rapid.

Summary

Soil and plant nitrogen studies have been conducted to obtain information pertinent to the application to field problems of the data determined by rapid chemical analyses. This report includes many of the results obtained in these studies. Tests on uncropped soils were undertaken to trace the variations of the available nitrogen supply in original air-dry soils and in soils which had received this nutrient as a fertilizer. Experiments were made to determine the rate of nitrification of ammoniacal nitrogen added to certain acid soils and also the extent of seasonal influences upon nitrogen availability.

The studies of uncropped soils have indicated that the nitrification of added ammoniacal nitrogen proceeds as a normal occurrence in the acid soils examined. The rate of nitrification is variable, and the process does not necessarily occur as a quantitative reaction.

Wide fluctuations have been noted in the analysis of uncropped soils sampled between short and long intervals of time. The long-range fluctuations may indicate the influence of seasonal differences. In general it was found that available nitrogen increases in the fall and winter, declines in late spring and continues through the summer.

Measurement of the availability of nitrogen by R.C.M. does not give the amount which may be available through a long period of time but merely gives the amount which is present at the moment. Levels of fertility have been suggested for this nutrient as determined by the chemical analysis.

In addition to the studies on uncropped soils, the fate of added nitrogen and the level of this nutrient in soils supporting plant growth were investigated. By growing sugar cane (H 109) in a series of Mitscherlich pots to which nitrogen was added, and by obtaining periodic samplings of soils and plant materials for nitrogen determinations, the rate of absorption and recovery of this nutrient were studied during the growth of a crop. Other studies included the relationship of fertilization to yield and composition of H 109 cane in pot growth, and the effect of single and split applications of nitrogen on the yield of this sugar cane.

These soil and plant nitrogen studies have indicated that when plants are growing in a soil, the available nitrogen level for that soil is usually low.

The cane plant can rapidly remove from the soil the available nitrogen which was either originally present or is later applied. The rate of absorption appears to depend upon the time of application with respect to the age of the plant or probably with the development of its root system, and is apparently independent of the needs of the plant.

Nitrogen absorbed beyond the requirements of the moment may be stored up and used for later growth. Thus it is possible for the cane plant to absorb nitrogen from one application at an early stage of its life and without further uptake continue to grow for a period which is probably dependent upon the quantity which had been absorbed.

The timing of the nitrogen application may be an important factor in the growth of cane; the efficiency of split versus single applications is in a measure dependent upon the time of application of the successive split portions.

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Trends in Irrigation Practice

By H. A. Wadsworth

Papers dealing with current irrigation practices with sugar cane in Hawaii were presented at the Annual Meetings of the Hawaiian Sugar Planters' Association in 1931 and 1932.* In addition to descriptions of irrigation practices then gaining favor with the industry, each report included a statistical summary of the areas served by each of the methods then in common use.

The purpose of the present paper is to review the same material after a lapse of five years, to report modifications in the trends suggested by the two reports which have been mentioned, and to note the effects of the changing emphasis of economic conditions and labor relationships upon the actual handling of water in the field.

Although it is probable that improvements in practice are too slow to justify such summaries every year, it is evident that considerable historic detail has been lost in the period since 1932. For example, the Koloa method, first developed in 1927, was used on about 20 per cent of the total irrigated area by 1931. By 1932 the area had increased to 25 per cent of the total. Less than one per cent of the total irrigated area was supplied by the Koloa method in 1937. A similar history of rapid expansion and equally rapid decline may be noted in the history of the Wailuku huli-huli method.

In retrospect it is not surprising that such rapid changes should have occurred. Increasing costs of water emphasize the necessity of careful use. Low sugar prices necessitate the reduction of costs of production. Whenever such prices prevail every effort is directed toward the end of cheap land preparation and the speeding up of the actual application of water. Labor shortages, present and imminent, demand the development of irrigation practices which may not only require a minimum of labor in irrigating but which may leave the fields as open as possible for the use of cultivating and harvesting equipment. The point of emphasis has changed frequently since about 1928. The industry is now faced with a situation necessitating the production of low-cost sugar with a minimum of labor. Irrigation practices are available if this is the only end desired, but other desirable characteristics, such as low cost of land preparation and extreme flexibility may, of necessity, be sacrificed toward that end.

Extension of Long-Line Practices:

Outstanding in almost universal acceptance by plantations during the past six years has been some form of the long-line method of irrigating. Although a standard practice with row crops in most irrigated areas the scheme of allowing water to seep into a soil only while water is flowing over it was not introduced into Hawaii

* Developments in Irrigation Practice (1931) H. A. Wadsworth and H. R. Shaw. Proceedings, Fifty-first Annual Meeting, Hawaiian Sugar Planters' Association; and a Report upon Progress and Performance of the Newer Methods of Irrigation (1932) H. R. Shaw. Proceedings, Fifty-second Annual Meeting, Hawaiian Sugar Planters' Association.

until about 1922 when the method was tried experimentally at Kilauea Sugar Plantation Company, Ewa Plantation Company, and Maui Agricultural Company. Since that time the expansion of the long-line method of irrigation has been phenomenal because it permitted marked reduction in irrigation costs during the period of low sugar prices. Since fields prepared for long-line irrigation not only require fewer man-days per crop in the actual application of water but also leave the field in fair shape for mechanical harvesting devices, the general scheme seems to be entering a new field of usefulness. From a small beginning in 1922, fields irrigated by the long-line method covered 5 per cent of the total irrigated cane area in 1931 and about 8 per cent a year later. The present summary indicates that almost 50 per cent of the irrigated cane land in Hawaii is irrigated by this method.

Such comparisons are difficult and not particularly reliable because of the terminology used in early reports. "No watercourse system," "automatic irrigation" and the "Baldwin flume system" were undoubtedly early efforts toward long-line distribution. Later terms such as "long contour" and "modified orchard" were attempts to distinguish between different general classes of long-line installations.

Valuable as these terminologies may have been during the formative stages of the practice they seem to have fulfilled their usefulness. In the present summary, long-line installations are divided into two classes: first, those in which the irrigation lines are supplied from a service ditch which is on the contour or nearly so; and second, those in which the irrigation lines are supplied from a service ditch which runs directly down the slope, the cane lines themselves leaving the service ditch at right angles or obliquely depending upon the topography and the desired slope in the lines. Ordinarily such an arrangement is called the "Herringbone layout."

Such a classification seems rational not because of any differences in the manner in which water is applied to the roots of the plant, but because of the different problems which are presented.

In the first case we have a supply ditch carrying water under a low velocity. No protection from erosion is necessary. The only problem, aside from those involved in establishing the proper slopes for the lines themselves, is to provide a sure and positive device for getting water through the ditch bank or over it in variable amounts, when delivery is desired. Ditch siphons, concrete or galvanized iron pipes fitted with gates of some sort or wooden boxes extending through the ditch banks are examples of these devices.

Long-Line Irrigations from Service Ditches on the Contour:

Two outstanding trends are to be noted in the handling of long-line irrigation. The first of these is the growing appreciation that the irrigator must have considerable leeway in the regulation of water admitted into each line. It is evident that on a given slope a smaller head of water must be used in a newly planted field because of danger of wash. And it is equally evident that a very large head is required when cane is heavy and recumbent. The amount that can be satisfactorily used increases with each irrigation.

As has been indicated the use of simple pipes through the ditch bank, which were either entirely open or completely closed has been almost completely abandoned in favor of pipes fitted with adjustable shutters of one sort or another. Moreover the

effective diameters of such pipes have been constantly increasing as experience is gained. Modern pipes are so large that concrete is the favored material.

In the Hamakuapoko section of Maui Agricultural Company the inlet pipes are complex in an effort to provide for the increasing head of water which may be used, and still permit rapid and accurate manipulation at the time of irrigating. In order to accomplish this end, the gate fitting consists of two parts. One of these is a shutter covering part of the pipe and held in place by a wing nut. The other is the conventional gate which is either entirely open or completely closed. In operation the irrigator opens the gates into as many lines as the water supply permits, and relies upon the inner shutter to regulate the flow in accordance with the particular demands of the line. Adjustments of the inner shutters are made as the crop demands. This type of ditch pipe is shown in Fig. 1.

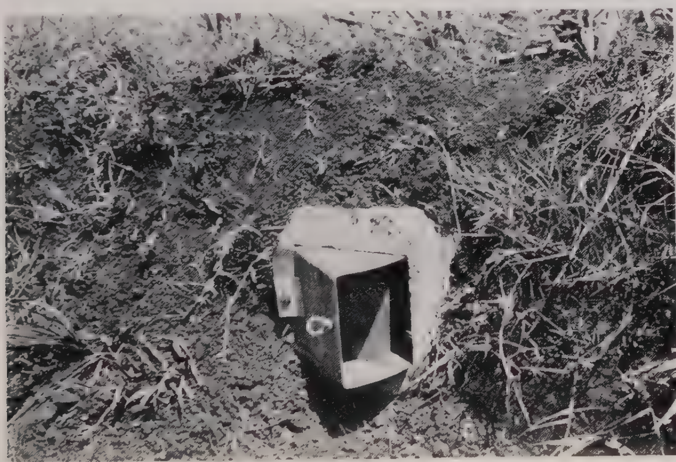

Fig. 1. A long-line service ditch fitting—Maui Agricultural Company. This fitting for a service ditch on the contour is featured by dual control. The inner gate, adjusted by the wing nut, is set to admit the proper amount of water to the line when the outer gate is open. The large concrete box shows the influence of increasing sizes in these fittings.

The other marked trend in long-line manipulation is a growing appreciation that speed in filling a long line on a slope is not the only desideratum. Since water can seep into the soil only during the time that water is flowing in the line, it is evident that this time must be long enough to provide adequate penetration. The evident procedure, if acceptable performance per man-day is to be secured, is to irrigate more lines at a time with a smaller flow in each. It is only in this way that increased acreage per man-day and adequate irrigation can be secured.

Simple as this conception may be it is difficult to modify the line-by-line concept of the irrigators themselves. Here, it would appear, is a fertile field for adult education.

An interesting development in the operation of long-line irrigation layouts is to be noted on plantations on the windward sides of Oahu and Kauai. In these areas

irrigation lines are at times drawn between adjacent cane rows in place of directly over the plants in deep and carefully maintained lines.

It is to be noted that a tough and relatively impervious subsoil, probably resulting from the intense rainfall, is to be found in the regions noted. Such a subsoil apparently modifies the seepage pattern resulting from long-line application and gives much greater lateral spread than would be expected with a deeper and more uniform soil. Good use is made of this unusual character at Kilauea Sugar Plantation Company. Here the plant crop is grown in lines similar to those used elsewhere but somewhat more shallow. During ratooning operations the line is filled and subsequent irrigations, during the life of the planting, are in temporary, shallow but broad lines drawn between the rows. Such a practice readily lends itself to mechanical cultivation.

Efforts to use this practice on the drier plantations have not been successful. In such cases the lateral seepage, even from wide shallow furrows seems insufficient to carry adequate moisture into the root masses directly under the plants. However, it is recognized that continued mechanical cultivation of old ratoons tends to result in flat culture of this sort.

Long-Line Irrigation from Service Ditches on the Slope:

In the second case, that is the case in which the service ditch runs directly down the slope, the problems are quite different and hydraulically much more difficult. Here the velocities are no longer negligible but may be very great. In one ditch at Wailuku Sugar Company, a velocity of more than 20 feet per second was noted. Not even the soils of Hawaii can withstand the erosive action of water under such velocities. Some sort of ditch lining is required in most cases although it is dispensed with in some. Great ingenuity has been shown in providing such lining. In the earlier installations this reinforcement was provided by wooden flumes framed in the shop and joined in the field on the selected location. Other more recent attempts have used concrete, sometimes cast into triangular flume sections and sometimes in trapezoidal form. In still other installations pipe either of concrete or steel is used. But in all cases the ends in view are to protect the ditch location from erosion and to increase the carrying capacity of a small ditch section to such an extent that ever-increasing areas can be served in a given time. One of the trends of the times is the growing appreciation that increased areas per man-day can only be secured if the man is supplied with a correspondingly increased quantity of water.

Providing facilities for removing water from the flume or pipe has given greater difficulty than providing the ditch reinforcement. When wooden flume is used, galvanized iron shutters which fold tightly against the side of the flume when the opening is to be closed and which divert any given amount into the lines adjacent as the shutters are swung out into the section, may be used. The work of H. W. Baldwin, of Maui Agricultural Company, with devices of this sort has been largely responsible for the success of this type of long-line irrigation.

The use of other materials than wood for flumes has necessitated the development of other devices for delivering water to the lines. At Waialua Agricultural Company, precast concrete sections of flume are cemented together in the field on the line of the service ditch. At five-foot intervals a section carrying an integrally

Fig. 2. Precast concrete flume—Waialua Agricultural Company. Here the water in the flume enters the box below and subjects the galvanized iron gates to some pressure. Discharge is controlled by manipulation of the gates. Such gates tend to leak, particularly after some use.

Fig. 3. Service flume with side ports—Waialua Agricultural Company. The tight-fitting slides prohibit leaks from the flume; the rolled top permits the use of an even, small flow in the flume.

cast cross box is installed. Being open to the flume by a port in the bottom, the cross box is under pressure when water is in the flume (Fig. 2). Delivery to the lines is made through galvanized iron gates which are installed at the ends of the box.

More recent practice at Waialua Agricultural Company involves the use of an almost rectangular, precast flume section provided with outlet ports on either side at five-foot intervals. Narrow slots cast in the outlet ports permit the insertion of plane iron shutters which regulate the flow with negligible leak under maximum

Fig. 4. Galvanized iron surface pipe—Honolulu Plantation Company. Here galvanized iron pipes, fitted at necessary intervals with tight slide gates, extend down the slope carrying water under considerable pressure. Note that the line is not completely buried.

Fig. 5. Discharge from surface pipe used as a service ditch—Honolulu Plantation Company. Here the velocity might result in considerable damage to the line, if it were not controlled as shown in Fig. 6.

pressure. Such a flume in use is shown in Fig. 3. The rolled top on the gate is used to deflect water toward the outlet port when great discharge is required or when the flume is practically empty.

In another ingenious device on the same plantation, the velocity of the water in the ditch is used to force a portion of the stream over the sides of the flume and into the cane rows. In order to accomplish this a T-shaped member of large-diameter galvanized iron pipe is so placed that the long arm extends up the ditch while the short arms span it and extend for some distance on either side. The velocity head

Fig. 6. Erosion control—Honolulu Plantation Company. Here the fast-moving jet from the partially opened port is introduced into a burlap sleeve and then delivered to the line.

Fig. 7. Opening a port in the surface pipe—Honolulu Plantation Company. Gates fit tightly to prevent leaks; a special tool is provided to adjust them.

of the water entering the submerged pipe is converted into pressure causing water to rise in the pipe to the elevation of the junction with the crossarm through which it flows over the sides of the flume and into the lines. It is evident that this scheme is suitable only for use with flumes carrying significant velocities.

When such flumes extend down slopes of varying gradient it is evident that the maximum capacity of the flume will be governed by the capacity of the section on the flattest slope. In some installations this difficulty is corrected by using flume sections of greater cross-sectional area on the flatter slopes, although this in extreme cases may be so costly as to be impractical. Another alternative lies in the use of pipe in place of flume. When pipes are used the capacity of the pipe is governed

Fig. 8. Pressure pipe delivery to long lines—Pioneer Mill Company. Water is delivered to long lines on either side of the pipe by manipulation of the metal gate sliding in a block cast to the pipe sections. Since the pipe is under pressure large heads of water can be handled and delivered to a number of lines at once.

mainly by its diameter and the total difference in elevation between the ends, and only slightly by differences in slope along the line.

Three notable examples of the use of pipe as a service ditch justify particular mention. Two of these, one at Honolulu Plantation Company and one at Pioneer Mill Company, differ only in the material used. At Honolulu Plantation Company heavily galvanized iron pipe of six-inch diameter is used. Twenty-foot lengths of this material can be easily carried and quickly assembled into a continuous leak-proof line by the use of cone and spigot couplings. Ports in either side, covered with shutters sliding in tight fittings (Figs. 4-7) permit the withdrawal of water for the lines which are conventionally located. At Honolulu Plantation Company the galvanized iron pipe is buried only when it crosses the ridge between adjacent lines. It is evident that water released through the ports will assume considerable velocity (Fig. 5) particularly along the lower ends of the pipe where the pressure is great. Erosion from this source is eliminated by the use of sleeves of burlap, as shown in Fig. 6, which are hung on the pipe and cushion the point of impact.

At Pioneer Mill Company concrete pipe is used in place of galvanized iron, as shown in Fig. 8. This pipe, cast on the plantation, is made in such lengths that a section, carrying side outlets covered with iron shutters, can be set at five-foot intervals. In operation the system is similar to that wherein galvanized iron pipe is used. When water is introduced at the upper end, the pipe is subjected to a pressure which, of course, varies with the vertical distance separating the surface of the water at the intake and the point in question. The varying discharge which would result if uniformly sized discharged ports were used can be corrected by adjustment of the galvanized iron slides which cover them.

Mention has been made of the pressure developed within lines laid in this manner. Although no local installations as yet demand great care in design to keep the

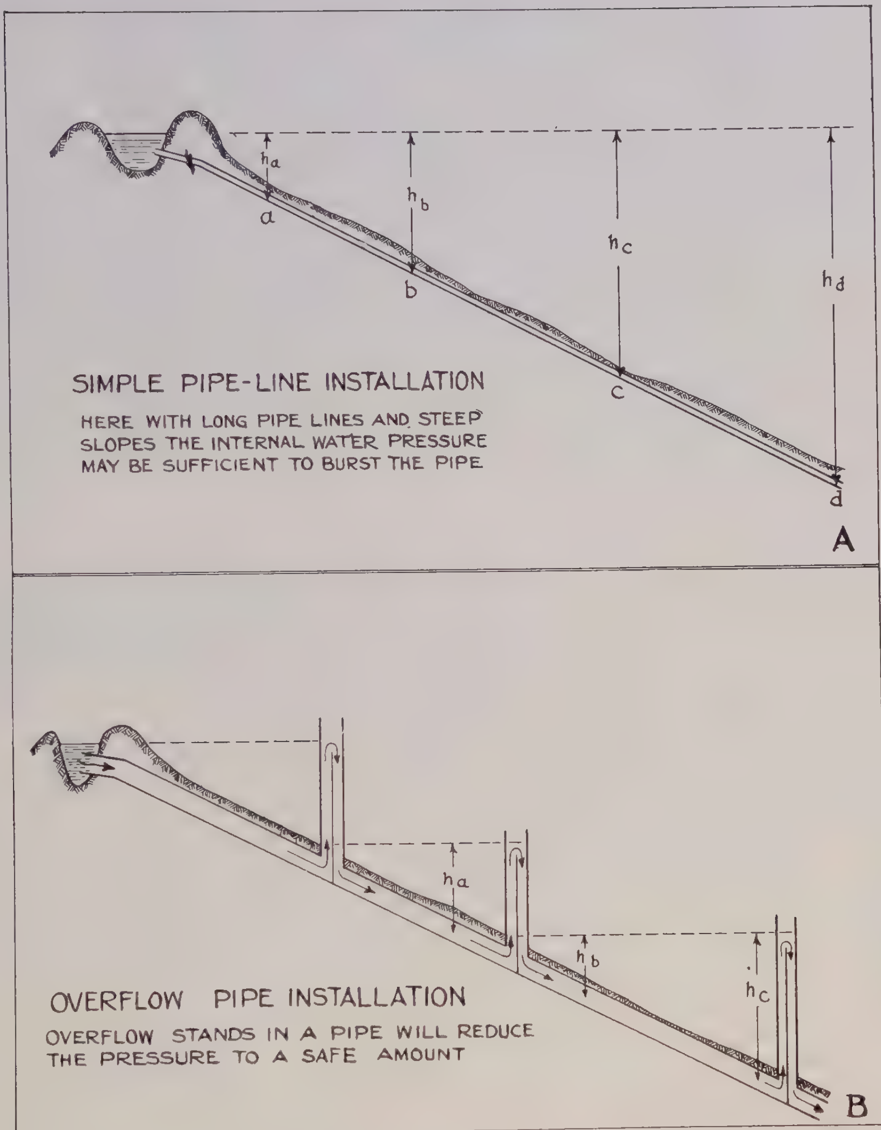

Fig. 9. Typical concrete pipe installations—diagrammatic representation of pressure relations in concrete pipe. Excessive pressure as in "A" can be avoided by use of overflow stands as suggested in "B."

pressure within the limit tolerated by the material in question, it is evident that extension of the practice may provide difficulties. Such a pipe is shown diagrammatically in Fig. 9. Here, in "A," a pipe line of indefinite length runs down a slope from a supply ditch, its end being "hd" feet vertically below the free-water surface. If all ports are closed at the time water is admitted, a condition which must be allowed for, the pressure, in feet of water, at any point is equal to the vertical distance separating that point from the free-water level. At the lower end the pressure is, of course, "hd" feet and intermediate pressures are as shown.

Fig. 10. An overflow stand—Pioneer Mill Company. When the wooden gate is lowered into the box, water rises above it, and submerges the large pipes leading to two-line borders on either side. This method, although costly, is highly effective in handling freshet flows.

Fig. 11. Concrete pipe in operation—Maui Agricultural Company. Manipulation of the gates in the bottom of the pipe permits delivery to either or both sides of the line. The handhole in the top allows for the removal of trash and for the adjustment of the gates. The plug at the left eliminates splash when the pipe is full.

Unreinforced concrete pipe, particularly if dry-mixed and hand-tamped, is not outstandingly high in tensile strength, nor are successive castings markedly uniform. Any section placed by chance in a location demanding a resistance to pressure greater than that built into the section must fail with concomitant cost and delay. It is doubtful if much of the plantation-made concrete pipe now in use has a tensile strength in excess of 35 pounds per square inch. If this be true it is evident that no single line should be long enough to create a difference in pressure of more than 80

feet at the head of the line. One should be quick to say that this figure of 35 pounds per square inch applies only to common pipe. By the use of a wet mix, machine tamping or internal reinforcing this figure can be greatly increased.

Methods of relieving this pressure are available. One common method is already in use at Pioneer Mill Company. Here the water is introduced into the line as usual but in place of being sealed throughout its length, the line is broken at frequent intervals by overflow stands. The pressure on any section may be reduced to any specified maximum by increasing the number of such stands. The simple hydraulics of the system is shown in Fig. 9-B.

Although this installation at Pioneer Mill Company illustrates the principle of overflow stands as a means for relieving pressure, it was not built for that purpose. A series of two-line borders were to be supplied with water from a ditch which might carry freshet water requiring expeditious handling. The pipe installed was of large diameter and so buried that when usable heads were used no discharge at the surface was possible in view of free discharge below. Overflow stands were so installed (Fig. 10) that when crude wooden gates were set in them the water rose in the upstream sides of the boxes and flowed over the gates into the pipe line below. When this was done concrete pipes leading from the overflow stand were submerged and delivery into the adjacent borders effected. Phenomenal increases in the area irrigated per man-day are reported for this practice. It is evident that the installation is costly in terms of dollars per acre.

Plantation-made concrete pipe, used as flume in the Hamakuapoko section of the Maui Agricultural Company, provides the third example of the use of such material as a service ditch on a significant slope. Here the pipe is not expected to operate under any great pressure head; in fact handholes in the top of the pipe as shown in Fig. 11 prevent the development of pressure. When cast in the yard (Fig. 12) each section is provided with two square holes in the bottom as well as the larger one in the top which has been mentioned. When installed the two bottom holes discharge water into a partitioned concrete saddle which delivers it to the lines on either side. Adjustment of water to the lines is effected by means of iron shutters which fit over the bottom openings in the pipe. The shutters can be operated by a heavy wire handle which extends beyond the pipe and which is shown in Fig. 13.

Irrigation by the Border Method:

An indicated in Table I, the area irrigated by the border method has increased markedly since 1932. From an area equal to 4.1 per cent of the total in 1932, the area irrigated by the border method in all its forms had increased to 9.3 per cent of the total in 1937.

It should be noted, however, that most of this increase is to be found in the use of two-line borders. In only one plantation has there been an increase in the area irrigated by four-line borders, between the dates of the two surveys.

There seems to be no consensus of opinion as to the apparent failure of the four-line borders to live up to their early promise. In many cases reported, particularly at Pioneer Mill Company and Lihue Plantation Company, the two inside lines, in a four-line border, have been definitely inferior. But whether this is due to the stimulation of the outside rows by the abundance of surface soil heaped up in the near-by

Fig. 12. Concrete pipe yard—Maui Agricultural Company. The pipe sections are cast with two square openings in the bottom and one in the top. (See Figs. 11 and 13.) Note the concrete box saddle in which the pipe rests and the unique serrated tops of the pipes.

Fig. 13. Concrete pipe for Herringbone layout—Maui Agricultural Company. Water in the pipe is delivered to the lines through the square saddle on which the pipe rests. Galvanized iron gates inside the pipe control the flow. They are operated from the outside by means of the heavy wire handle.

ridge, or to the loss of surface soil in the center of the border, or to unsatisfactory distribution of water is not clear. Moreover some plantations, particularly Hawaiian Commercial and Sugar Company have experienced great difficulty with erosion within the borders. Here care and money were freely spent in the building of cross dams and barriers of trash and lumber to reduce erosion to a tolerable degree.

Two-line borders are of increasing popularity. At Pioneer Mill Company and Ewa Plantation Company this method of irrigation is being used not only on slopes

too steep for the four-line borders but also in topography which seems well adapted to the wider border. It is evident that the difficulty of having the two interior lines inferior disappears when the narrower border is used.

It is also evident from a scrutiny of the local history of the method, that borders were often established on slopes that were too steep for the securing of adequate penetration. The apparent correction of irrigating many borders simultaneously, toward the ends of increased penetration and elimination of erosion, is being practiced at Ewa Plantation Company.

However, the fact remains that borders lend themselves to mechanical cultivation. A spinner similar to those used on many plantations is shown in operation in Fig. 14.

Fig. 14. Weed eradication in young ratoons in borders—Ewa Plantation Company. Spinners and other mechanical cultivators find great use in fields laid out for irrigation by the border method.

Two-line borders, served from the concrete, overflow pipe line which has been mentioned, have been satisfactory at Pioneer Mill Company. Ditch water available for this area is subject to great variations in flow. Freshets of a few hours' duration are not uncommon; a means for distributing this water quickly must be provided. With the two-line contour borders on such flat slopes that erosion is minimized, it is evident that a large stream of water can be handled by one man when the overflow gates are properly manipulated. It is said that some fields at Pioneer Mill Company provided with irrigation by this means have been brought to maturity with but three man-days of irrigation labor per acre during the life of the crop.

Overhead Sprinkling:

Recent developments in overhead sprinkling equipment on the mainland, and the local incentive to perfect a method of irrigation which will not only require a minimum of labor in irrigating but will also leave the field clear of internal structures, again draws attention to the possibilities of this long-debated method. The use of

this method of irrigating has increased markedly in recent years on the mainland because of improved equipment. Such equipment, which has led to the use of portable sprinklers, with great reduction in first cost, has extended the possibilities of overhead sprinkling into such low-value crops as alfalfa, beans, and sugar beets.

Two developments have made this possible. The first of these is the perfection of a light, thin-wall, large-diameter pipe which can be used in temporary field lines and which because of its large diameter may serve many modern sprinklers simultaneously. The ends are reinforced with special fittings which permit the rapid assembly of a leak-free line.

The other important development lies in the improvements in the heads themselves. Modern heads are large, heavy and relatively costly. Some of them deliver as much as 50 gallons per minute under a pressure of about 50 pounds per square inch. With such heads it is possible to get acceptably uniform coverage over an area 150 feet in diameter.

A field equipped for modern overhead sprinkling is provided with a single pressure line along the upper edge of the field, fitted with capped outlets at intervals of about 125 feet. Lines of portable pipe which at times are 1000 feet long, if pressure permits, are connected to each of these in turn. These portable lines are provided with fittings into which vertical pipes, carrying the sprinkler, may be screwed. Under the conditions noted, such pipes, or risers, would be about 125 feet apart. Ordinarily two lengths of portable pipe are provided, one being placed while the other is in use.

It is clear that such a practice differs widely from the overhead installations formerly used with sugar cane in Hawaii. Emphasis has previously been laid upon the design and use of inexpensive heads with small diameters of coverage. The lack of uniform coverage secured from them and the complexity of the pipe system required to serve them contributed largely to the disappointment resulting from their use. As has been indicated, modern heads sacrifice low first cost to wide coverage and uniformity of distribution. Since a permanent installation of pipe for heads of such heavy discharge is economically impractical, a portable system is indicated. The development of the light pipe, with the quickly operated couplings which have been mentioned, make such portable lines possible.

Certain values may be anticipated from the use of modern overhead sprinkling methods with sugar cane. Although no figures are available for the labor requirements with this method in sugar cane, it seems probable that they will not exceed those of the better long-line installations. Moreover the area must lend itself to economical animal and machine cultivation because of the complete absence of permanent structures inside the field. For the same reason mechanical harvesting may be more expeditious.

High in the list of possible disadvantages is first cost which may range from $60 to $100 an acre, according to the inadequate figures available. Since each area is a special problem requiring its own design, uniform first costs are improbable. In fortunate cases in which gravity pressure is available the first cost may be considerably less than that given.

A small area of about four acres is now under modern overhead irrigation at Waialua Agricultural Company. The extension of this area to a size suitable for

detailed cost studies is proposed. The adoption of this method on other areas of similar size at Kekaha Sugar Company and at Grove Farm Company is under consideration.

Small as the area at Waialua Agricultural Company is, it may well be that the four acres reported for modern overhead sprinkling, marks the beginning of an important trend in Hawaii.

Table I gives the area of land in sugar cane in Hawaii irrigated by the several methods. Here the areas are distributed by islands. In Appendix A the island totals are-distributed among the plantations.

Trends in Ditch Lining:

Increased appreciation of the value of water at critical periods and the advent of better sugar prices have stimulated ditch-lining programs which were reported as being held in abeyance in the 1932 report. During the five-year period ending in 1937, seepage protection was provided for almost one million lineal feet of Hawaiian plantation ditch. This is an increase of 38 per cent over the figure given for 1932.

In accordance with the scheme used in 1932 an attempt has been made to separate the ditches into "Main Canals" and "Field Ditches," although this has not always been possible. The results of the present census of ditch lining in Hawaii are given in Table II. Figures contributing to the totals given in Table II are given in Appendix B.

Although the totals for linings of the several sorts, given in Table II, are reported to the nearest foot, no such precision should be read into them. In some cases precise figures were available; in others approximations only were possible. The totals given in Table II are simple summations of the detailed figures reported and may not be reliable beyond the first two figures given.

TABLE I

Acreage of Sugar Cane Irrigated on Hawaiian Plantations by Various Methods, by Islands

Method Used	Hawaii	Kauai	Maui	Oahu	Total 1937	Total 1932	Per cent change based on 1932 return: Increase	Per cent change based on 1932 return: Decrease
Single-line Contour:	1,069	6,201	9,794	5,698	22,762	33,652	..	32
Cut Lines:								
2 lines cut	....	5,272	6,772	805	12,849	31,191	..	59
4 lines cut	....	4,049	....	6,509	10,558	....	..	..
8 lines cut	....	....	....	....	....	8,326	..	..
More than 8 lines cut*	968	223	732	1,748	3,671	17,317	..	79
Long Lines:								
Service ditch on contour	4,911	20,081	14,324	17,348	56,664	10,030	465	..
Service ditch on slope (Herringbone):								
Service Flume:								
Wood	....	10	160	16	186	....	..	..
Concrete	....	305	168	2,478	2,951	....	..	.
Other Material	....	526	25	76	627	....	..	..
Service Pipe:								
Concrete	....	....	897	....	897	....	..	..
Iron	....	....	....	752	752	....	..	..
Koloa:	....	1,244	....	....	1,244	32,969	..	96
Border:								
Service Ditch on Contour:								
4-line borders	....	144	218	6,432	6,764	4,873	39	..
2-line borders	....	46	3,607	826	4,479	495	805	..
Service Ditch on Slope (2-line borders):								
Wooden Flume	....	....	58	....	58	57	2	..
Concrete Pipe	....	....	336	....	336	....	..	..
Overhead Sprinkling	198	....	....	4	202	445	..	55
Total	7,146	38,071	37,091	42,692	125,000	129,355		3.3

* Including that previously listed as Wailuku huli-huli.

TABLE II

Ditch Linings on Hawaiian Sugar Plantations, by Islands

Type of Lining	Ditch Lining Complete in Lineal Feet						Per cent change based on 1932 return	
	Hawaii	Kauai	Maui	Oahu	Total 1937	Total 1932	Increase	Decrease
Main Canals:								
Concrete Cast in Place	17,803	125,598	471,294	103,549	718,244	601,486	19	..
Precast Slabs	4,450	....	29,615	11,880	45,945	57,278	..	20
Cut Stone*	31,106	18,600	19,289	269,011	338,006	261,793	29	..
Cement Plaster	185,063	800	123,180	128,881	437,924	507,800	..	14
Concrete Pipe	....	....	5,327	39,270	44,597	....	..	..
Other Material	27,929	7,750	27,955	154,168	217,802	115,686	88	..
Total for Main Canals	266,351	152,748	676,660	706,759	1,802,518	1,544,043	17	..
Field Ditches:								
Concrete Cast in Place	....	2,500	92,120	6,876	101,496	12,935	680	..
Cut Stone	....	31,000	9,322	92,078	132,400	8,600	1,440	.
Cement Plaster	....	....	324,106	3,160	327,266	69,942	368	..
Wood	....	....	130,028	34,891	164,919	152,777	8	..
Concrete Pipe	....	....	118,869	28,613	147,482	....	..	..
Total for Field Ditches	....	33,500	674,445	165,618	873,563	244,254	258	..
Pipe Lines:								
Pump Lines	18,765	35,542	136,678	203,640	394,625	334,716	18	..
Field Lines, including Siphons	....	53,510	16,456	96,182	166,148	144,607	15	..
Total for Pipe Lines	18,765	89,052	153,134	299,822	560,773	479,323	17	..
Grand Total	285,116	275,300	1,504,239	1,072,199	3,236,854	2,267,620	43	..

* Including field rock.

Fig. 15. Precast concrete slabs for ditch lining — Wailuku Sugar Company. These slabs, carrying interior reinforcing of poultry wire, are light and easily laid. They increase the carrying capacity of the ditch and protect it from erosion.

Fig. 16. Backfilling around a precast slab ditch—Wailuku Sugar Company. The template holds the loosely placed slabs to the required cross section while dirt is tamped behind them.

Fig. 17. A precast slab ditch in operation —Wailuku Sugar Company. The iron structure in the foreground permits the delivery of part of the water into level ditches on either side without excessive disturbance to the lines of flow. Here the water had a velocity of 20 feet per second.

Fig. 18. Precast concrete slab ditch—Kohala Sugar Company. The iron gate fitting into the bottom of the section is similar to that shown in use in Fig. 17. Gates of this type permit the removal of a part of the total amount in the flume with a minimum of splash.

But even with this qualification some trends are to be noted. Apparently field ditches have received more attention than main canals during the period. The length of lined field ditches increased 250 per cent while lined main canals were increased by 17 per cent. It is undoubtedly true that the main canal systems are more completely lined than the field ditches and have consequently needed less attention.

The favored materials in lining main canals have been concrete, cast in place, and cut stone. A significant decrease in the main ditches lined with precast concrete slabs and cement plaster is to be noted. Concrete cast in place and cut stone have also been popular in lining field ditches but with smaller ditches the cement plaster linings have been of greatest use. The length of field ditches lined with this material has increased almost fourfold since 1932.

Of note too, in the survey of trends is the increasing use of concrete pipe in field ditches. More than 100,000 feet of this material is noted in 1937. Practically none of this material was reported in similar service in 1932.

Modern precast concrete slabs, carrying reinforcing poultry wire, shown in Figs. 15-18, have also been widely used in field ditch-lining programs, particularly at Wailuku Sugar Company.

Trends in Land Reclamation:

Although not land reclamation in the sense that arid lands are provided with irrigation facilities or swamp lands freed from salts and surplus water, mention should be made of the modern trend of improving land by the careful trapping of sediment in freshet flows. At Ewa Plantation Company and at Kekaha Sugar Company intricate flood canals are provided so that occasional freshet waters charged with valuable sediments may be led into great stilling basins where the sediment is dropped. Considerable valuable cane land has been added to the cropped area at Ewa Plantation Company during recent years by this procedure. At Kekaha Sugar Company flood ditches are carefully cleaned prior to the season during which freshets may be expected in order that a high velocity within the stream may keep the silt in suspension until the proper point for deposition is reached.

At Ewa Plantation Company reservoir sediments are used toward the same end. The workman shown in Fig. 19, working with a fire hose connected to a portable, gas-driven pump, is washing out the sediments which have collected in the reservoir during 30 years of constant use. The drainage water heavily charged with this sediment is carried to the thin soils of the coral fields or to others where a top dressing of good soil would be of value. The additional benefit resulting from increasing the capacity of the reservoir is evident.

Water-Measuring Programs:

Without consideration of the details of the water-measuring equipment of the plantations as given in Table III, it is possible to note the trends in local practice. Outstanding is the increasing popularity and use of the Parshall flume. First introduced in 1927, the use of this device has increased regularly. The decrease in the use of weirs of various types and submerged orifices is largely accounted for by the substitution of Parshall flumes. The use of Parshall flumes practically doubled in

Fig. 19. Reservoir cleaning with a high pressure water jet—Ewa Plantation Company. In addition to increasing the capacity of the reservoir this practice permits the building up of thin soils on the coral fields.

Fig. 20. A concrete Parshall flume—Grove Farm Company. The Parshall flume, either of concrete or wood, is rapidly becoming the standard water-measuring device on Hawaiian Plantations. Four hundred of them are now in use.

the five-year period since the last census. Four hundred flumes, 337 of them being of concrete, were reported in 1937. A typical Parshall flume installation is shown in Fig. 20.

Since the Parshall flume gives only an instantaneous rate of flow, some form of water-stage register is required for an accurate determination of total quantity. In this field various models of the Stevens water-stage register have had almost universal acceptance on Hawaiian plantations.

TABLE III

Water-Measuring Devices in Use on Hawaiian Sugar Plantations, September 1, 1937

Type of Device	Hawaii	Kauai	Maui	Oahu	Total 1937	Total 1932	% change based on 1932 return Increase	Decrease
Weirs								
Rectangular	31	42	21	26	120	217	..	44
Triangular	..	..	..	..	..	6	.	.
Submerged Orifices	..	..	..	..	..	664	..	..
Fixed Area	..	..	1	119	120	..	..	70
Adjustable Area	..	..	..	73	73	..	..	..
Rated Sections	2	23	23	7	55	61	..	10
Parshall Flumes								
Wood	2	12	40	10	64	60	7	
Concrete	12	25	234	70	341	108	210	.
Venturi Meters	1	5	26	57	89	70	27	
Integrating Devices								
Great Western	..	..	..	163	163	422	..	61
Reliance	..	..	..	39	39	39	..	.
Pipe Line	..	4	..	18	22	..	.	.
Water-Stage Registers								
Stevens	8	43	75	53	179	170	5	..
Friez	..	..	16	2	18	20	..	10
Gurley	10	5	..	17	32	36	..	11
H.S.P.A.	6	..	4	24	34	..	..	..
Brown	..	..	10	..	10	12	..	17

It should be noted that the Venturi meter holds its preeminent position as a measuring device in pipe installations particularly on pump discharge lines.

Trends in Water and Labor Economy:

Since 1931 the increasing use of the newer methods of irrigation has naturally resulted in the accumulation of considerable information with respect to their value in water and labor administration. On Maui, for example, where more than half of the irrigated acreage is served by some form of long-line or border method, such large areas are available for comparison that some confidence may be placed in the results. Table IV* gives the results of such comparisons. The figures are self-explanatory. It should be mentioned, however, that the areas involved in the long-line and border summations involve a greater percentage of plant and young ratoon crops than is the case with contour lines.

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* Condensed from data supplied by F. W. Broadbent, Hawaiian Commercial and Sugar Company.

TABLE IV

Comparative economies in water and irrigation labor as related to irrigation methods on Maui Plantations

Method	Plantation	Acres irrigated per Man-Day	Yield, Tons per Acre		Acre-inches Irrigation water per			Acres involved in Averages
			Cane	Sugar	Acre	Ton Cane	Ton Sugar	
Contour Lines	Pioneer Mill Co.	1.3	85.7	9.87	283.7	3.31	28.7	666.4
	Wailuku Sugar Co.	2.4	45.4	6.00	232.5	5.12	38.7	14.2
	Maui Agr. Co.	1.5	80.9	11.53	223.8	2.76	19.4	293.4
	Hawn. Com. & Sugar Co.	1.5	79.7	11.50	279.5	3.50	24.3	999.9
	Average or Total	1.7	72.9	9.72	254.9	3.67	27.8	1,973.9
Long Lines	Pioneer Mill Co.	4.9	76.0	8.08	243.9	3.21	30.2	277.6
	Wailuku Sugar Co.	5.1	68.7	6.90	138.4	2.01	20.0	166.1
	Maui Agr. Co.	4.6	84.9	10.59	206.1	2.43	19.6	241.2
	Hawn. Com. & Sugar Co.	3.6	92.7	13.34	316.9	3.42	23.7	1,535.2
	Average or Total	4.5	80.6	9.70	226.3	2.77	23.4	2,220.1
Border	Pioneer Mill Co.	7.7	92.7	9.97	268.1	2.89	26.9	585.1
	Wailuku Sugar Co.	7.7	64.4	7.65	123.0	1.91	14.8	134.3
	Maui Agr. Co.	4.7	89.3	12.40	204.7	2.29	16.5	49.4
	Hawn. Com. & Sugar Co.	6.1	87.1	13.01	252.2	2.89	19.3	1,084.9
	Average or Total	6.5	83.4	10.8	212.0	2.50	19.4	1,853.7

More direct evidence of the interrelation between the adoption of the newer methods of irrigation and the irrigation labor requirements is provided in Table V and in the first eight columns of Table VI. In each of the plantations reported the spread of the newer methods has been reflected in a significantly reduced labor expenditure in irrigation.

TABLE V

Labor utilization as related to the adoption of the newer methods of irrigation.
Hawaiian Commercial and Sugar Company

Crop	Acres Irrigated	Per cent of Area in Newer Systems	Man-Days Irrigating Per Ton Cane	Man-Days Irrigating Per Ton Sugar	Man-Days Irrigating Per Acre
1931	7,863	0	0.42	3.0	29
1932	7,726	0	0.41	2.9	31
1933	7,843	7.2	0.33	2.2	24
1934	7,905	17.1	0.31	2.1	22
1935	6,714	32.9	0.27	1.8	21
1936	6,572	45.6	0.23	1.6	20

TABLE VI

Labor utilization as related to the adoption of the newer methods of irrigation.
Ewa Plantation Company

Year	Acres Irrigated	Per cent of Area in Newer Systems L-L	Per cent of Area in Newer Systems Border	Man-Days Irrigating Per ton Cane	Man-Days Irrigating Per ton Sugar	Man-Days Irrigating Per Acre	Man-Days Per Acre for all other operations*	Total Man-Days Per Acre for Year
					Annual Basis			
1931	7,991	1.1	8.8	.20	1.61	19.6	49.9	69.5
1932	8,169	1.3	30.0	.17	1.35	17.4	49.0	66.4
1933	8,422	1.7	45.6	.14	1.05	13.2	46.3	59.5
1934	8,348	2.3	56.7	.10	.75	8.8	45.3	54.1
1935	8,043	2.3	68.2	.07	.57	6.4	43.3	49.7
1936	8 354	5.3	70.6	.09	.70	7.1	43.1	50.2
					Crop Basis			
1934	8,348	2.3	56.7	.16	1.25	14.7	44.9	59.7
1935	8,043	2.3	68.2	.10	.83	9.3	45.0	54.3
1936	8,354	5.3	70.6	.08	.66	6.5	39.6	46.2

* Including planting, weeding, fertilizing, and harvesting.

It seems evident from Table IV and the more detailed figures from Tables V and VI that the newer methods have lived up to their early promise with respect to their economy of labor in water distribution. It is also clear that this economy has been accompanied with significant decreases in the amount of water required for the production of a ton of cane or a ton of sugar. Moreover the average yields in both cane and sugar have increased with the adoption of the newer methods although closer scrutiny indicates that this is not always true when the plantations are considered individually, nor is it necessarily true that this increase has been brought about entirely by the modification in irrigation methods.

APPEN

Acres of Sugar Cane Irrigated by Various Meth

Plantation	Total Area Irrigated	Single-Line Method	Cut-Line Methods 2 Lines	4 Lines	More than 8 cut Lines	Service Ditch on Contour
Maui:						
Hawaiian C. & S. Co...........	13,958	4,722	....	....	....	6,215
Maui Agricultural Co..........	8,945	5,072	....	....	....	3,656
Wailuku Sugar Co.............	4,340	....	....	....	732	3,402
Pioneer Mill Co...............	9,848	....	6,772	....	....	1,051
Total 1937	37,091	9,794	6,772	....	732	14,324
Hawaii:						
Kohala Sugar Co..............	4,586	....	....	....	225	4,261
Honokaa Sugar Co.............	1,167	1,069	....	....	....	....
Paauhau Sugar Plantation Co...	1,393	....	....	....	743	650
Total 1937	7,146	1,069	....	....	968	4,911
Oahu:						
Ewa Plantation Co............	8,906	....	....	1,754	....	499
Honolulu Plantation Co........	5,107	....	....	....	385	3,599
Kahuku Sugar Co..............	4,040	....	....	....	1,100	2,780
Oahu Sugar Co................	10,803	5,213	....	....	....	5,539
Waialua Agricultural Co.......	9,834	460	....	4,755	263	1,759
Waianae Co.	1,352	....	805	....	....	547
Waimanalo Sugar Co...........	2,650	25	....	....	....	2,625
Total 1937	42,692	5,698	805	6,509	1,748	17,348
Kauai:						
Grove Farm	1,732	141	....	....	....	1,444
Hawaiian Sugar Co............	5,659	5,508	....	....	....	151
Kekaha Sugar Co..............	7,158	....	....	4,049	....	3,109
Kilauea Sugar Co..............	3,950	....	....	....	....	3,750
Koloa Sugar Co................	2,555	552	....	....	....	1,519
Lihue Plantation Co.[4].........	11,368	....	5,272	....	....	5,972
McBryde Sugar Co.............	5,113	....	....	....	....	3,823
Waimea Sugar Co.[3]............	536	....	....	....	223	313
Total 1937	38,071	6,201	5,272	4,049	223	20,081

1 Including 999 acres 3-line borders.

2 Including 50 acres with other materials.

3 Not reported in 1932.

4 Including Makee Sugar Co.

DIX A

ods on Hawaiian Plantations, September 1, 1937

Long-Line Methods						Border Method				
Service Ditch on Slope (Herringbone)						Service Ditch on Contour		Two-Line Borders Service Ditch on Slope		Overhead Sprinkling
Service Flume			Service Pipe							
Wood	Concrete	Other Material	Concrete	Iron	Koloa	4-Line	2-Line	Wooden Flume	Concrete Pipe	
....	38	....	....	....	....	218	2,765[1]	....	....	....
87	130	....	....	....	....	....	....	....	....	....
37	....	....	....	....	....	....	169	....	....	....
36	....	25	897	....	....	....	673	58[2]	336	....
160	168	25	897	....	....	218	3,607	58	336	....
....	....	....	....	....	....	....	....	....	....	100
....	....	....	....	....	....	....	....	....	....	98
....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	198
....	....	....	....	....	....	6,264	389	....	....	....
....	....	76	....	752	....	168	127	....	....	....
....	160	....	....	....	....	....	....	....	....	....
....	12	....	....	....	....	....	39	....	....	....
16	2,306	....	....	....	....	....	271	....	....	4
....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....
16	2,478	76	....	752	....	6,432	826	....	....	4
....	....	147	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....
....	....	200	....	....	....	....	....	....	....	....
....	305	179	....	....	....	....	....	....	....	....
10	....	....	....	....	....	114	....	....	....	....
....	....	....	....	....	1,244	....	46	....	....	....
....	....	....	....	....	....	....	....	....	....	....
10	305	526	....	....	1,244	114	46	....	....	....

APPENDIX B

Ditch Lining in Use on Hawaiian Plantations in Lineal Feet

Plantation or Water Company	Main Canals: Concrete Cast in Place	Main Canals: Precast Slabs	Main Canals: Cut Stone	Main Canals: Cement Plaster	Main Canals: Concrete Pipe	Main Canals: Other Material	Field Ditches: Concrete Cast in Place	Field Ditches: Cut Stone	Field Ditches: Cement Plaster	Field Ditches: Wood	Field Ditches: Concrete Pipe	Pipe Lines: Pump Lines	Pipe Lines: Field Lines Including Siphons
Hawaii:													
Hawaiian Irrigation Co.[1]	500	....	....	166,030	....	12,356	....	....	....	....	....	....	....
Kohala Sugar Co.	5,650	4,450	....	....	....	1,530	....	....	....	....	....	18,765	....
Kohala Ditch Co.	11,653	....	31,106	19,033	....	2,420	....	....	....	....	....	....	....
Paauhau Sugar Plantation Co.	....	....	....	....	....	11,623[6]	....	....	....	....	....	....	....
Kauai:													
Grove Farm	14,400	....	....	800	....	1,650	....	....	....	....	....	....	....
Hawaiian Sugar Co.	....	....	....	....	....	....	....	7,500	....	....	....	1,142	7,360
Kekaha Sugar Co.	13,000	....	....	....	....	....	2,000	....	....	....	....	20,000	3,000
Kilauea Sugar Co.	....	....	....	....	....	....	....	....	....	....	....	....	....
Koloa Sugar Co.	23,000	....	18,600[7]	....	....	4,100	....	14,000[7]	....	....	....	800	20,350
Lihue Plantation Co.	16,421	....	....	....	....	....	....	....	....	....	....	3,000	3,000
McBryde Sugar Co.	58,777	....	....	....	....	2,000	500[2]	9,500	....	....	....	8,800	19,800
Waimea Sugar Mill Co.	....	....	....	....	....	....	....	....	....	....	....	1,800	....
Maui:													
East Maui Irrigation Co.	106,760	....	....	60,546	....	....	....	....	....	....	....	....	3,328
Hawaiian C. & S. Co.	126,924	4,615	2,368	37,204	....	....	....	....	318,940	15,542	570	58,715	....
Maui Agricultural Co.	63,050	....	900	25,440	1,861	4,310	17,415	....	....	18,700	13,433[3]	47,425	....
Pioneer Mill Co.	116,560	....	13,421	....	1,766	22,145	3,305	7,322	966	4,786	104,666	30,538	11,428
Wailuku Sugar Co.	58,000	25,000	2,600	....	1,700	1,500	71,400[2]	2,000	4,200	91,000	200	....	1,700
Oahu:													
Ewa Plantation Co.	20,639	....	23,297	1,769	1,294	61,198	....	....	1,720	24,000	1,567	24,288	....
Honolulu Plantation Co.	....	11,780	....	....	....	1,785	....	....	....	....	....	36,050	25,710
Kahuku Sugar Co.	10,100	....	....	....	....	....	....	....	1,440	....	18,900[3]	16,894	....
Oahu Sugar Co.	20,398	100	76,288	....	....	....	....	83,598	....	....	7,922	65,244	31,855
Wahiawa Water Co.	3,046	....	....	....	15,023	....	....	....	....	....	....	....	....
Waiahole Water Co.	6,000	....	88,715	55,368	....	308	....	....	....	....	....	1,700	9,034
Waialua Agricultural Co.[4]	2,935	....	74,567[5]	71,744	19,937	....	....	....	....	....	....	50,383	21,333
Waianae Co.	16,631	....	6,144	....	3,016	90,877	6,876	8,480	....	10,891	224	4,881	8,250
Waimanalo Sugar Co.	23,800	....	....	....	....	....	....	....	....	....	....	4,220	....
Total 1937	718,244	45,945	338,006	437,924	44,597	217,802	101,496	132,400	327,266	164,919	147,482	394,625	166,148

[1] Including Honokaa Sugar Co.

[2] Precast concrete slabs.

[3] Concrete flume.

[4] At Waialua Agricultural Co. it is impossible to list main canals and field ditches separately.

[5] Including 27,867 feet stone rubble.

[6] Half pipe, concrete.

[7] Field rock.

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Wood
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APPENDIX C

Water-Measuring Devices in Use on Hawaiian Pl

Plantation or Ditch Company	Weirs		Submerged Orifices			Parshall Flumes	
	Rectangular	Trapezoidal	Fixed	Adjustable	Rated Sections	Wood	Concret
Hawaii:							
Hawaiian Irrigation Co.	2	..	..	..	..	..	..
Honokaa Sugar Co.	..	..	..	..	..	..	..
Kohala Sugar Co.	..	..	..	..	..	1	8
Kohala Ditch Co.	29	..	..	..	2	1	4
Paauhau Sugar Plantation Co.	..	..	..	..	..	..	..
Kauai:							
Grove Farm	..	..	..	..	..	..	3
Hawaiian Sugar Co.	18	..	..	..	..	..	..
Kauai Water Co.	3	..	..	..	5	..	6
Kekaha Sugar Co.	6	..	..	..	..	..	10
Kilauea Sugar Co.	..	..	..	..	..	9	5
Koloa Sugar Co.	..	..	..	..	5	3	1
Lihue Plantation Co.	9	..	..	..	..	..	..
McBryde Sugar Co.	6	..	..	..	13	..	..
Waimea Sugar Mill Co.	..	..	..	..	..	..	..
Maui:							
East Maui Irrigation Co.	2	..	..	..	9	1	..
Hawaiian C. & S. Co.	..	..	1	..	11	6	113
Maui Agricultural Co.	..	..	..	..	1	..	18
Pioneer Mill Co.	16	..	..	..	2	16	80
Wailuku Sugar Co.	3	..	..	..	..	17	23
Oahu:							
Ewa Plantation Co.	1	1	80	..	..	5	..
Honolulu Plantation Co.	1	..	..	..	..	..	..
Kahuku Sugar Co.	..	..	..	..	..	..	..
Oahu Sugar Co.	11	..	37	67	..	2	..
Wahiawa Water Co.	..	..	..	..	1	..	..
Waiahole Water Co.	8	..	2	6	5	2	..
Waialua Agricultural Co.	1	..	..	..	1	..	65
Waianae Co.	..	..	..	..	..	..	5
Waimanalo Sugar Co.	4	..	..	..	..	1	..
Total	120	1	120	73	55	64	341

ntations, September 1, 1937

	Integrating Devices			Water-Stage Registers				
Venturi Meters	Lyman	Reliance	Pipe Line	Stevens	Friez	Gurley	H.S.P.A.	Brown
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	3	..	..	6	..
1	..	..	..	5	..	10	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	3	..	..	..	..
..	..	..	..	11	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	5	..	..	..	..
..	..	..	..	..	..	5	..	..
..	..	..	..	..	..	..	..	..
5	..	..	4	24	..	..	..	..
..	..	..	..	..	..	..	..	..
..	..	..	..	8	4	..	..	..
10	..	..	..	24	..	..	1	..
1	..	..	..	18	..	..	1	..
15	..	..	..	19	..	..	2	10
..	..	..	..	6	12	..	..	..
17	90	..	..	3	..	2	..	..
16	..	..	..	..	..	1	..	..
5	..	..	..	..	..	..	..	..
10	67	37	14	..	..	..	..	..
1	..	..	..	..	..	..	..	..
1	6	2	..	2	..	12	2	..
6	..	..	..	44	..	..	22	..
1	..	..	4	3	..	..	..	..
..	..	..	..	1	2	2	..	..
89	163	39	22	179	18	32	34	10

Such comparisons of the labor involved in irrigating, leading as they do to expression in some such unit as acres irrigated per man-day, are confusing and may be misleading in the long run. Irrigation by the old contour-line method was a slow procedure, as the figures indicate. Only a limited amount of water could be delivered to the individual irrigator and while that small flow was running into the lines, there was opportunity for such a necessary operation as weeding.

With more modern methods the tempo of irrigation has been stepped up. Increasing the area that a man may irrigate from 1.7 acres per day to perhaps four times that area, as indicated by the experiences on Maui, must be at the sacrifice of such opportunity for weeding. Although the labor, actually charged to irrigation, has decreased significantly with the adoption of faster irrigation procedures it would appear that other labor charges should appear if the fields are to be maintained in their usual condition.

The period characterized by such modifications in irrigation practice has seen great advances toward the end of cheap and expeditious weed eradication. Mechanical cultivators powered either by animals or light tractors, as well as devices permitting the inexpensive handling of chemical sprays, have so reduced the labor cost of weed control that it becomes impossible to note the effect of the additional weeding, which may be necessary with modern irrigation methods, in the annual labor charges for cultivation.

Regardless of how such charges are distributed it seems evident from the last two columns of Table VI that the adoption of new methods of irrigation and the perfection of cultivation procedures have reduced the total labor cost in growing an acre of sugar cane.

At Ewa Plantation Company, the effort required to irrigate an acre of cane, on the annual basis, decreased from 19.6 man-days in 1931 to 7.1 man-days in 1936, or a decrease of 64 per cent. During the same period and with the same limitation, the total labor per acre decreased from 69.5 man-days to 50.2 man-days or a reduction of 28 per cent. The labor benefits of the newer irrigation methods are evident although figures for man-days spent in irrigating may apparently be misleading if used alone.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 16, 1937 TO SEPTEMBER 15, 1937

Date	Per Pound	Per Ton	Remarks
June 16, 1937 .	3.455¢	$69.10	Puerto Ricos, 3.45; Philippines, 3.45; Cubas, 3.46.
" 17	3.45	69.00	Philippines.
" 18	3.455	69.10	Philippines, 3.45; Puerto Ricos, 3.45; Cubas, 3.46.
" 24	3.45	69.00	Philippines; Puerto Ricos.
July 1	3.485	69.70	Puerto Ricos, 3.47; 3.50.
" 2	3.505	70.10	Philippines, 3.50; Puerto Ricos, 3.50; Cubas, 3.50; 3.51.
" 8	3.51	70.20	Cubas.
" 19	3.42	68.40	Cubas or Duty Frees.
" 27	3.45	69.00	Philippines.
" 28	3.4867	69.73	Virgin Islands, 3.45; Philippines, 3.50; Cubas, 3.51.
" 29	3.50	70.00	Philippines.
Aug. 4	3.53	70.60	Philippines.
" 5	3.50	70.00	Cubas or Duty Frees.
" 11	3.59	71.80	Cubas.
" 13	3.55	71.00	Philippines.
" 17	3.5867	71.73	Philippines, 3.55; Puerto Ricos, 3.60; Cubas, 3.61
" 18	3.605	72.10	Cubas, 3.60; 3.61.
" 26	3.555	71.10	Philippines, 3.55; Cubas, 3.56.
" 27	3.55	71.00	Puerto Ricos.
" 31	3.50	70.00	Philippines.
Sept. 3	3.505	70.10	Philippines, 3.50; Cubas, 3.51.
" 13	3.45	69.00	Philippines.
" 15	3.415	68.30	Philippines, 3.40; Cubas, 3.43.

INDEX TO VOLUME XLI

(An asterisk preceding a page number indicates that the article is illustrated.)

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